HB 1303 Interim Report:

A Comprehensive Assessment of the Impacts of Climate Change on the State of Washington

Prepared by the University of Washington JISAO CSES Climate Impacts Group

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Climate Science
in the Public Interest

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1. Study Authorization and Charge

On April 20, 2007, the State Legislature of Washington passed HB 1303 which mandated the preparation of a comprehensive assessment of the impacts of climate change on the State of Washington. HB 1303 specifically requested that the Departments of Community, Trade, and Economic Development and Ecology work with the Climate Impacts Group (CIG) at the University of Washington to produce this comprehensive assessment. The assessment is to be focused on the impacts of global warming generally, and specifically in relation to public health, agriculture, the coastal zone, forest ecosystems, infrastructure, and water supply and management. The Bill further requires that the departments indicated and the CIG consult with state and local public health and resource planning and management agencies. If adequate funding is not available to complete all of the elements identified, the departments and the CIG are required to list and prioritize which research projects have the greatest cost/benefit ratio relative to planning decisions. Work that is completed by December 1, 2007 must be included in the final report of the Washington Climate Change Challenge and all work is to be completed by December 15, 2008. In addition to the requirements specified in HB 1303, this study is coordinated with elements of the Governor's Executive Order 07-02, which formed the Preparation/Adaptation Working Groups (PAWGS). The CIG provided technical support for the PAWGs as discussed in Section 4.b and will utilize PAWG recommendations in adaptation work planned for 2008.

2. Report Scope

This interim report identifies, based on work to date, impacts of climate change over the next 50 years on eight sectors including Hydrology, Agriculture, Salmon, Forests, Coasts, Infrastructure, Energy, and Human Health. It provides an early outlook on the direction of the study, and key findings as of December 2007. In addition, each sector has briefly addressed adaptation, and where appropriate, the CIG HB1303 sector role in PAWGs. These are preliminary results and subject to further refinement with remaining work in 2008.

3. Key Findings

Climate change is causing and will continue to cause significant changes in temperature, precipitation and related variables (e.g. streamflow) across the State. Based on results from a number of Global Climate Models (GCMs), we can expect annual temperature to increase approximately 0.5°C, or roughly 1.0°F, per decade over the next 50 years. Our best estimate of annual precipitation, on the other hand, is that it is likely to remain roughly the same as in the 20th Century. Some models indicate large increases in winter precipitation and some also indicate large decreases in summer precipitation. Our best estimate of sea level rise for most coastal waters of Washington is 15cm (6 inches) by 2050 and 35cm (14 inches) by 2100, though we cannot rule out much higher rates of sea level rise, say 1.2m (4 feet) by 2100.

Preliminary evaluations of the impact of climate change on each sector are presented in Section 6; however, key findings include but are not limited to the following:

a) Hydrology – Reduced snowpack and changes in soil moisture will occur; warmer temperatures and reduced snowpack will alter the flow regime in snowmelt dominant and transient (rain/snow) watersheds.
b) Agriculture and Irrigation Agriculture/Economics – Warmer temperatures and changes in snowpack will cause water availability to decline during parts of the growing season; diseases and pests may be more problematic; and, changes in climate will force some changes in agricultural practices.
c) Salmon – Warmer air temperatures will cause stream temperatures to increase, in some cases above critical thresholds for fish survival; in addition, changes in streamflow timing and volume may cause stress to fish life cycles.
d) Forests – Warmer temperatures will cause decreases in lower elevation forest productivity, increases in wildfire frequency and area, increases in tree mortality due to insects, and changes in species distribution and composition.
e) Coasts – Sea level rise and the associated coastal changes are projected to happen gradually over time; however, the coast is particularly sensitive to low-frequency high-impact storm and erosion events that are difficult to predict.
f) Infrastructure – Global climate models predict that storm intensity will generally increase over the next 50 years and lack of planning for climate change by municipalities and the high cost of stormwater systems in the State are likely to exacerbate impacts of climate change.
g) Energy – Heating degree days will continue to be the dominant energy-related factor over the next 50 years, but cooling degree days become a much more important factor in eastern WA as the region warms
h) Human Health – Adverse health effects from increasingly intense heat waves, poor air quality, and possible increased flooding are likely to become a greater problem.

4. Study Structure

The following section describes the connections between the various sectors that constitute the CIG HB1303 study, and describes the organization of this report. It also describes the relationship between this study and the PAWGS formed under Governor's Executive Order EO 07-02.

a. CIG HB1303 Team

The project team formed to carry out the CIG HB1303 study uses an integrated assessment approach structured around scientific expertise within the CIG, as well as at Washington State University and Pacific Northwest National Laboratory. The project consists of eight sector groups, in addition to a Climate Scenarios Working Group that serves all other sectors by providing projections of future regional climate downscaled to the state of Washington, and an Adaptation Group that will begin looking at issues in 2008 related to preparing for climate change. The eight sectors are Hydrology, Agriculture, Salmon, Forests, Coasts, Infrastructure, Energy, and Human Health. Members of the Agriculture, Coasts, Forests, Human Health, and Hydrology sectors serve on each of the parallel PAWGS.

b. Relationship of Work to Preparation/Adaptation Working Groups (PAWGs)

The CIG HB1303 sectors encompass the range of issues addressed by the PAWGs. However, the charge of the CIG HB1303 study is primarily to provide scientific expertise regarding the likely impacts of climate change over the next 50 years on each of the sectors and implications for adaptation. CIG representatives serve on each of the five PAWGs (Agriculture, Coasts and Infrastructure, Forest Resources, Human Health, and Water Resources) to provide future climate projections, scientific information on each sector, and critical reviews of PAWG recommendations. The CIG HB1303 sectors roughly parallel the five PAWGs in terms of areas of impact, although several of the PAWG areas are partitioned into additional sectors in the CIG HB1303 study. Figure 4.1 summarizes the relationships between the CIG HB 1303 sectors and the PAWGs.

In addition, CIG has contributed climate and adaptation information to the PAWG process. CIG summarized extensive internal and external research on 20th and 21st Century climate and impacts in a document titled *Climate Facts* (Climate Impacts Group 2007). CIG also provided key adaptation principles from the CIG/King County guidebook *Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments* (Snover et al. 2007, http://cses.washington.edu/cig/fpt/guidebook.shtml), which was published in September 2007. Finally, CIG provided updated climate scenarios and sector-specific impact baselines for the final PAWG report, which will be completed in February 2008.

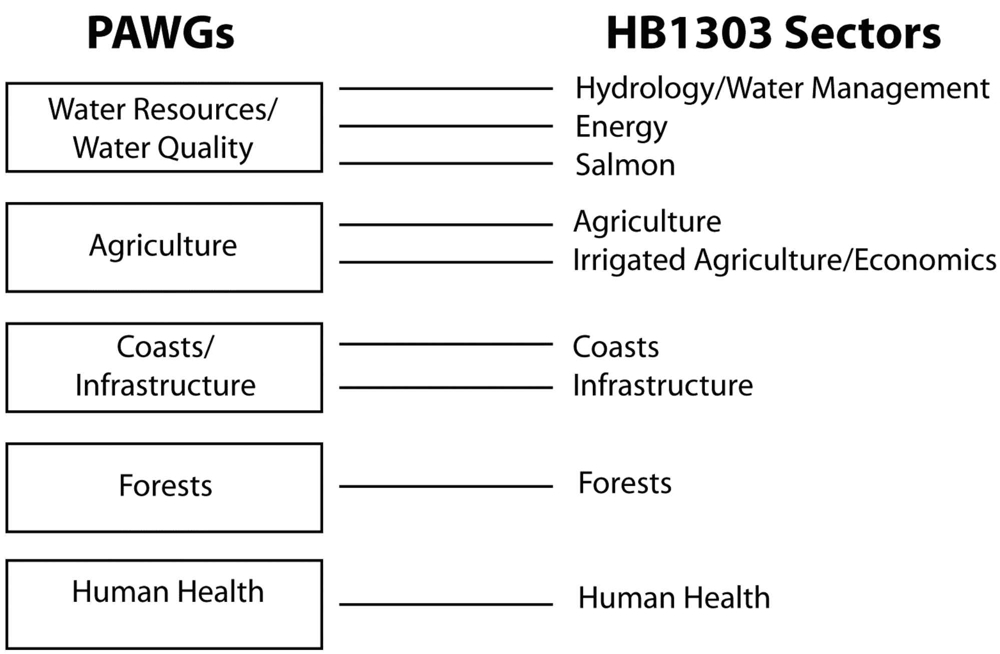


Figure 4.1. Relationships between Executive Order 07-02, Climate Preparation/Adaptation Working Groups (PAWGs) and CIG HB1303 Sectors.

5. Future Scenarios and Climate Projections

This section corresponds with Task 1 of the of the Statement of Work (SOW), dated July 2007, which calls for construction of climate change scenarios, via methods to be identified by the Scenarios Working Group, appropriate to each of the CIG HB1303 sectors. They are tailored to some extent to the types of models and other predictive methods outlined for each sector (described in Sections 6a-h). Overall, they range from sophisticated statistical and dynamic downscaling methods in the case of some sectors (e.g., hydrology) to the specification of general ranges of climate change for others (e.g., human health). In all cases, however, we draw our information from Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) global scenarios, downscaled to the regional (state) and/or finer level. This new work is grounded in methods previously published by the Climate Impacts Group and others.

a. Background

To support the impacts assessment work by the various sectors, the Scenarios Working Group is assembling and downscaling climate change projections for the 21st Century. Climate change scenarios are based on simulations performed for the IPCC AR4. The climate model output resolution is too coarse for regional studies (typically about 1-3 degrees or roughly 100-300 km (62-186 mi) spatial resolution, depending on the specific climate model), and is being downscaled using two different approaches: an empirical method and a regional climate model. For analyzing GCM output and comparing with observations, we use a domain larger than the state of Washington (Pacific Northwest), bounded by latitudes 41.5° and 49.5°N and longitudes 111° and 124°W. The larger domain is chosen because some models have too few grid cells in the state of Washington to perform meaningful analysis, and the distinctions in simulated climate changes between the state-scale and the regional scale are probably not meaningful.

21st Century simulations are based on scenarios for future emissions of greenhouse gases developed by the IPCC (Nakicenovic et al. 2000) and incorporated in climate model runs archived for AR4. Among the IPCC global emissions scenarios for the next century, we selected scenarios referred to as B1 and A1B. B1 represents a slower increase in greenhouse gas emissions with stabilization of CO2 concentrations by 2100. A1B has higher emissions but is not the highest of IPCC scenarios; most modeling groups ran only A1B, A2, and B1. Both 20th Century (also called retrospective) and 21st Century climate simulations by 20 different global climate models have been performed for IPCC and archived by the Program for Climate Model Diagnosis and Intercomparison (PCMDI) for these emissions scenarios, and we are basing our regional scenarios on this suite of simulations.

The GCM-based descriptions of climate changes for the Pacific Northwest are now complete and ready for statistical and dynamical downscaling; we summarize the changes projected by the 20 models, focusing on a weighted average, or composite. The weighting is based on performance of each model in simulating the observed climate of the 20th Century in the PNW and also how far the model's 21st Century simulation is from the multi-model average; greater weights in the composite are given to the better-performing models. For details see Mote et al. 2007. Monthly changes in temperature and precipitation, based on the weighted composite, were utilized in a delta method approach to make preliminary estimates of the impact of climate change on the sectors. Further discussion of this approach is provided in Sections 5e and 6.a.iii.

b. Climate of the 20th Century

GCMs that accurately reproduce the climate of the past century may be better suited to accurately predict 21st century climate. Model performance is evaluated on seasonal and annual mean temperature and precipitation, based on the difference between the regional-mean simulated and observed (NCEP reanalysis) values for the period 1970-99. Models range from 3.4°C (6.1°F) too cold to 3.5°C (6.3°F) too warm, with many models producing a temperature bias less than 1°C (1.8°F) (Fig 5.1A). Models tend to be too wet on average, but most models show a bias of less 10cm/yr (Fig 5.1B). This information, in addition to statistical analysis of 21st Century simulations, helps us to decipher the results of the numerous scenarios available from the IPCC AR4.

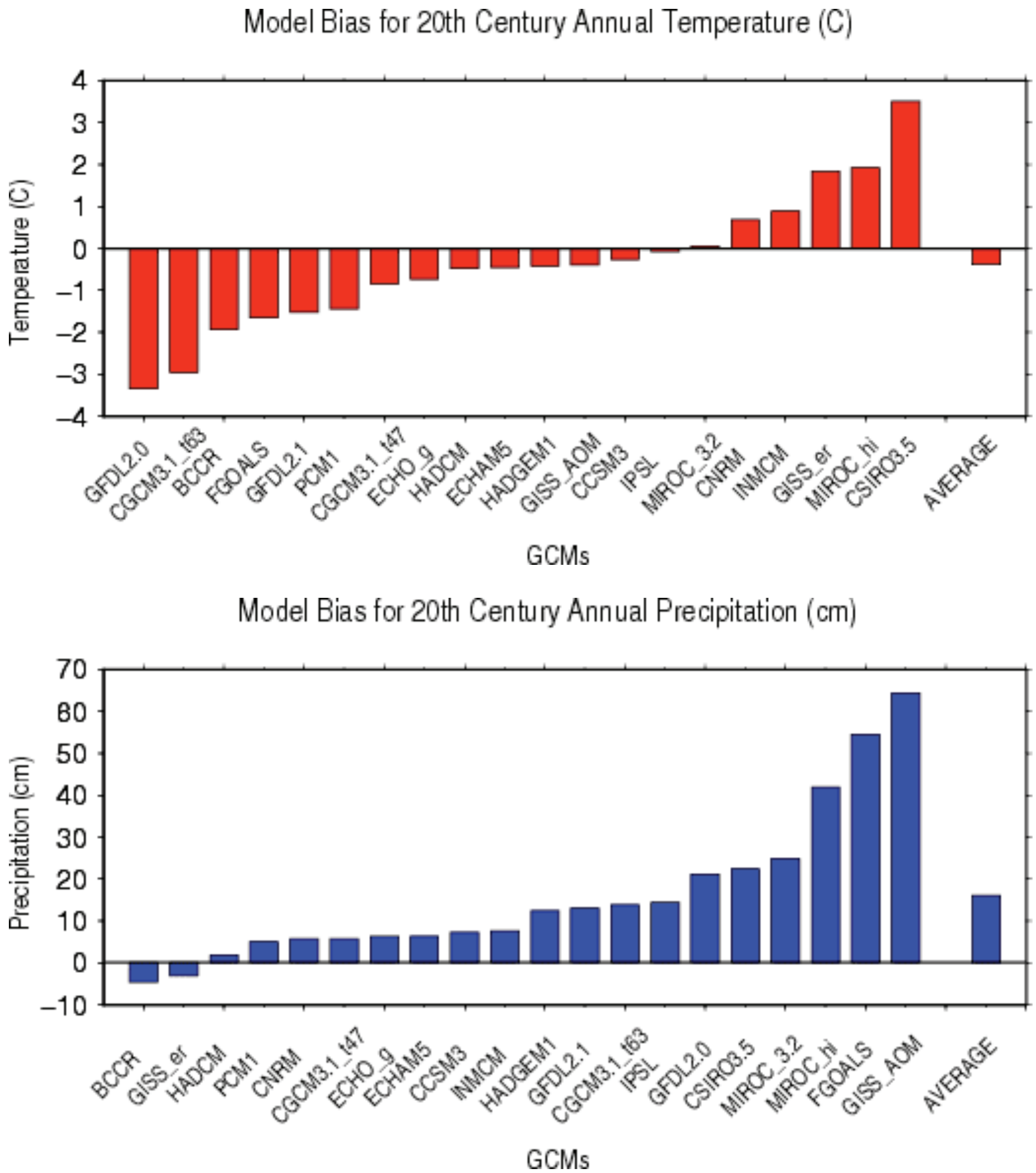


Figure 5.1. A(top) and B(bottom): Model bias, relative to observations, for 20th-Century simulations of temperature (A) and precipitation (B) averaged over the Pacific Northwest.

c. Climate of the 21st Century

To describe the slow, anthropogenic change in the climate at various future time intervals, we use 30-year averages which remove most of the year-to-year and decade-to-decade variations that naturally occur in the climate. We compare future changes with the average from 1970-1999. The near future (roughly 20 years from now) is represented by the average from 2010-2039, the midrange (roughly 40 years from now) is represented by the average from 2030-2059, and the distant future by the average from 2070-2099.

Changes in temperature and precipitation (Fig. 5.2) are generally consistent with previous results for the region based on a smaller set of global models (http://www.cses.washington.edu/data/ipccar4/). Before about 2030 there is little difference in warming rates between the B1 and A1B scenarios, but by 2050 the differences in the means and the extremes amount to 1°C (1.8°F) or more. In the B1 scenario, stabilizing greenhouse gases means that the temperature also stabilizes by the end of the century. In every scenario, the future warming greatly exceeds natural variability. For precipitation this is not the case; the range of simulated precipitation could increase substantially or decrease substantially but the weighted-average annual mean change is small throughout the 21st Century.

The new modeling work reveals important seasonally varying changes. For temperature, the greatest warming is simulated for summer months (Table 5.1). For precipitation, there is considerable spread among models, but a slightly greater likelihood of modest increases in winter and modest decreases for summer (Table 5.2).

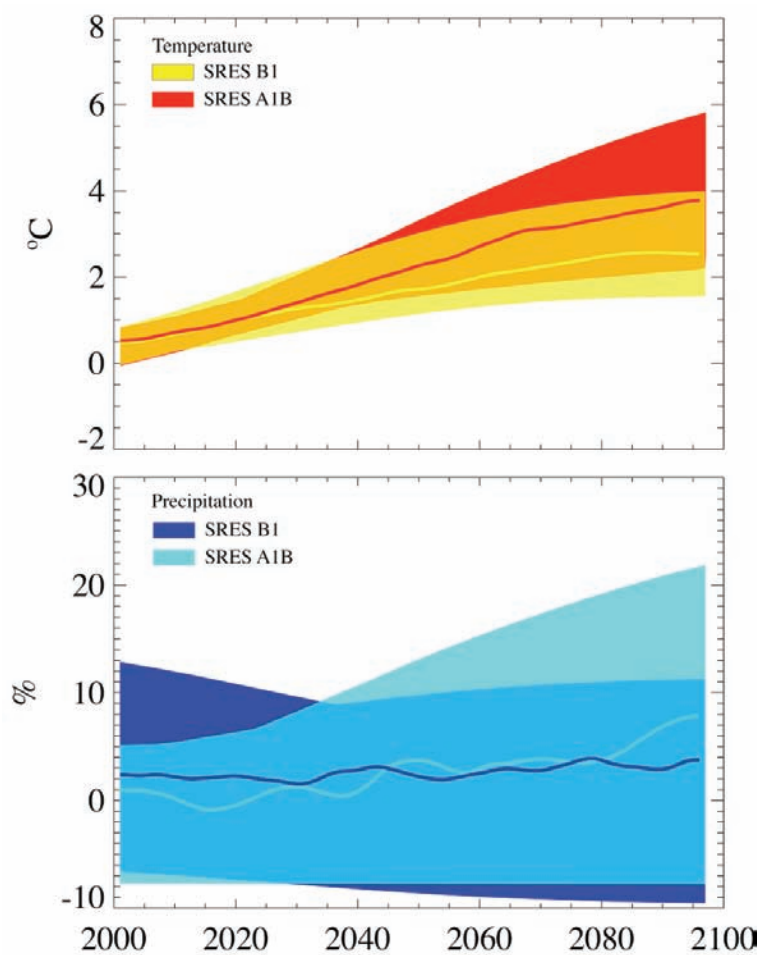


Figure 5.2. Changes in Pacific Northwest annual temperature (top) and precipitation (bottom) for IPCC global emissions scenarios B1 and A1B.

Table 5.1. Mean and range of future annual and seasonal temperature changes (in °C and °F) for the 2020s and 2040s, relative to 1970-1999. Projections are based on 20 GCMs running B1 and 19 running A1B. Two IPCC emissions scenarios (B1 and A1B) were chosen to bracket the likely range of greenhouse gases.

Season	2020s: Temperature in °C (°F)			2040s: Temperature in °C (°F)		
	B1	**A1B**	**Range**	**B1**	**A1B**	**Range**
Annual	**+1.2** (2.1)	**+1.3** (2.3)	**+0.6 to +1.9** (1.1 to 3.4)	**+1.7** (3.1)	**+2.3** (4.1)	**+0.9 to +2.9** (1.6 to 5.2)
Winter Dec - Feb	**+1.0** (1.8)	**+1.0** (1.8)	**+0.4 to +2.0** (0.7 to 3.6)	**+1.4** (2.5)	**+1.8** (3.3)	**+0.6 to +2.8** (1.0 to 5.1)
Spring Mar - May	**+1.1** (2.1)	**+1.1** (1.9)	**+0.2 to +2.0** (0.4 to 3.6)	**+1.5** (2.7)	**+1.8** (3.3)	**+0.6 to +3.0** (1.0 to 5.4)
Summer Jun - Aug	**+1.4** (2.5)	**+1.8** (3.2)	**+0.5 to +2.9** (1.0 to 5.2)	**+2.1** (3.7)	**+2.8** (5.0)	**+0.9 to +4.4** (1.5 to 7.9)
Autumn Sep - Nov	**+1.0** (1.8)	**+1.0** (1.8)	**+0.1 to +1.8** (0.1 to 3.2)	**+1.4** (2.6)	**+1.9** (3.5)	**+0.8 to +2.9** (1.4 to 5.2)

Table 5.2. Mean and range of future annual and seasonal precipitation changes (in %) for the 2020s and 2040s, relative to 1970-1999. Projections are based on 20 GCMs running B1 and 19 running A1B. Two IPCC emissions scenarios (B1 and A1B) were chosen to bracket the likely range of greenhouse gases.

Season	2020s: Precipitation change, %			2040s: Precipitation change, %		
	B1	**A1B**	**Range**	**B1**	**A1B**	**Range**
Annual	**+1.8**	**+0.1**	**-9 to +10**	**+2.1**	**+2.0**	**-10 to +11**
Winter Dec - Feb	**+2.0**	**+2.1**	**-14 to +23**	**+2.6**	**+5.1**	**-13 to +27**
Spring Mar - May	**+1.3**	**-0.3**	**-11 to +9**	**+3.3**	**+3.9**	**-11 to +16**
Summer Jun - Aug	**-3.0**	**-7.9**	**-30 to +13**	**-4.6**	**-12.0**	**-30 to +17**
Autumn Sep - Nov	**+5.9**	**+2.8**	**-11 to +20**	**+5.1**	**+4.7**	**-10 to +21**

d. The Coastal Ocean: Sea Level Rise and Sea Surface Temperature

For marine ecosystems and other aspects of coastal issues, sea surface temperature (SST) is an important quantity. All GCMs used in this report have a fully resolved ocean model, typically with resolution of 1 degree (roughly 100 km or 62 mi) or less in latitude or longitude. Figure 5.3 shows the mean SST from the 20-model average for the late 20th century (black line and grey shaded area) and for the 2040s. Although the increases are only about 1.5°C (2.7°F), less than over land, they are substantially larger than the natural variability, which will pose challenges to marine ecosystems.

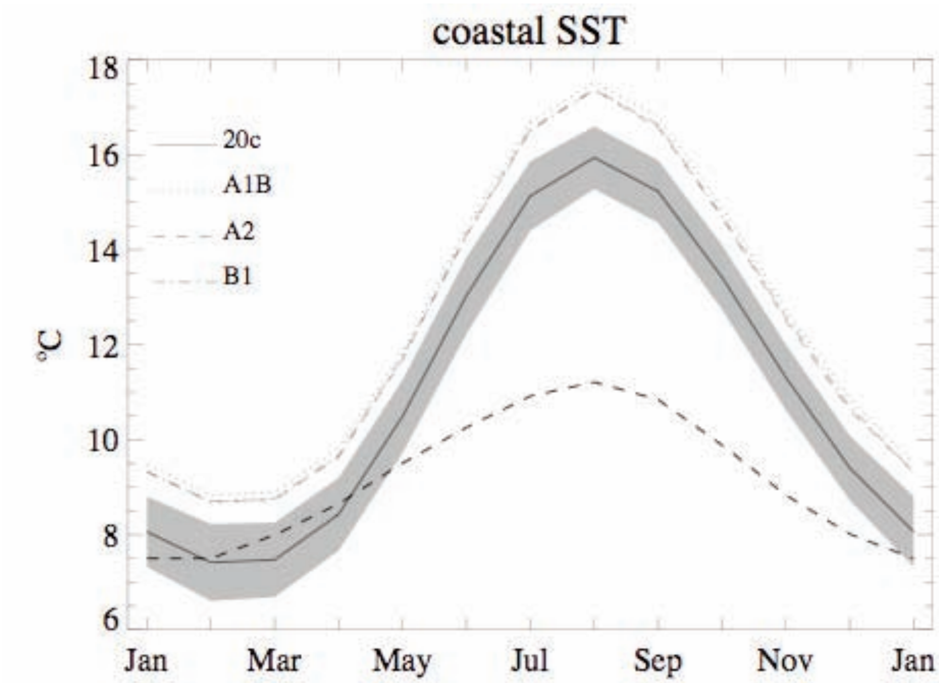


Figure 5.3. Simulated annual cycle of coastal sea surface temperature (SST) on Washington's coast, from the ocean component of each GCM. Black curve shows the multi-model mean for 1970-99 and grey shading shows the range (mean plus and minus one standard deviation). Dashed line shows observed SST from Race Rocks lighthouse near Victoria BC, for 1970-99. Future (2040s) SST for three IPCC scenarios is shown for the multi-model mean.

Local sea level rise (SLR) is produced by the combined effects of global sea level rise and local factors such as vertical land deformation (e.g., tectonic movements, isostatic rebound) and seasonal ocean elevation changes due to atmospheric circulation effects. Sea level rise scenarios for Washington State were developed using a combination of these global and local factors. The Forth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) projects global SLR over the course of this century to be between 18 and 38 cm (7-15 inches) for their lowest emissions scenario, and between 26 and 59 cm (10-23 inches) for their highest emissions scenario. For coastal decisions with long timelines and low risk tolerance, it is important to consider low-probability high-impact estimates that take into account the potential for increased melt rates of the Greenland and Antarctic ice sheets as well as local atmospheric changes. Combining the IPCC high emissions scenario with the above factors, a low-probability high-impact estimate of local SLR for the Puget Sound Basin is 53 cm (21 inches) by 2050 and 124 cm (48 inches) by 2100. Estimates are smaller for the central and southern Washington coast and even lower for the northwest Olympic Peninsula due to tectonic uplift (see CIG Sea Level Rise summary (forthcoming)).

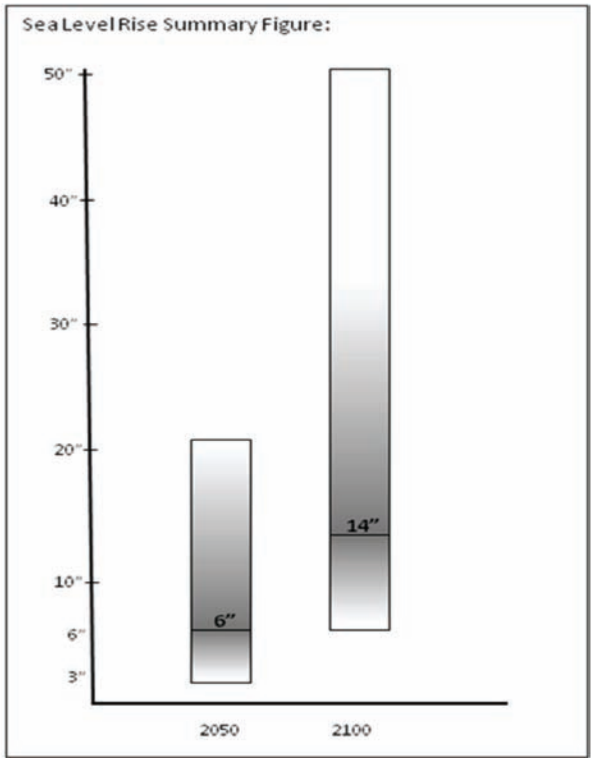


Figure 5.4. Projections of sea level rise, in inches, for Washington for 2050 and 2100. Shading qualitatively indicates estimated likelihood with the endpoints judged highly unlikely.

e. Downscaling

Preliminary work has been performed to produce high-resolution downscaled output (to 1/16th degree latitude-longitude, or about 6 km (3.7mi)) from each of the 20 GCMs and two emissions scenarios over Washington. A preliminary composite of the downscaled GCM output, using a delta method approach, is incorporated in results presented by most of the sectors. In this approach, historical temperature and precipitation inputs are scaled up or down based on the monthly or seasonal (depending on the sector) composite changes predicted by the suite of GCMs. This approach does not utilize downscaled output from each GCM and, therefore, shortcuts many of the details of the overall downscaling approach. However, it does provide a useful preview of the more detailed results that will follow in 2008.

6. Sector Interim Results and Findings

This section addresses Task 2 of the Scope Of Work dated July 2007 and contains interim reports and key findings from each of the eight sectors (Hydrology, Agriculture and Irrigated Agriculture/Economics, Salmon, Forests, Coasts, Infrastructure, Energy, and Human Health). Following the integrated assessment model, climate projections developed by the Climate Scenarios Working Group were used by each sector to direct research and develop key findings. Results provided here are based on preliminary analysis, which can provide a useful preview of the more detailed results that will be completed over the next year and will be included in the final report.

a. Hydrology

i. Management/Decision Context and Research Needs

Climate change has and will continue to impact water resources of the Pacific Northwest with implications for the timing and quantity of snow accumulation, soil moisture, and streamflow. Changes in water availability in turn will impact all resources that rely on surface water. Recent climate change projections from IPCC AR4 and improved hydrologic modeling capabilities provide a capability for simulating past and future hydrology of the state at a finer scale (5km by 6km, or 3mi by 3.7mi) than has been previously been possible. Predictions of hydrologic variables such as snowpack, soil moisture, potential evapotranspiration, vapor pressure deficit, and streamflow, at 1/16th degree scale for three 2020s, 2040s and 2080s will allow for evaluation of climate change impacts on agriculture, hydropower, anadromous and resident fish, forests, infrastructure, and coasts across the State as well as at the regional and watershed scale.

ii. Research Questions Addressed under HB1303

The overarching research question to be addressed by this sector is: *How will the hydrology of the major rivers of the state respond to climate change over the next century, and how effectively will the state's physical water management infrastructure be able to respond to these changes?*

Subsidiary research questions include:

a) What are the impacts of climate change on flood frequency of Washington rivers?
b) What are the impacts of climate change on drought frequency?
c) What are the impacts of climate change on water management risk in select river basins?

iii. Scientific Progress and Key Findings

Expected overall impacts of climate change on Washington State hydrology were determined using the delta method approach to produce 1/16th degree daily temperature and precipitation fields for the 2020s and 2040s, for both of the two greenhouse gas emissions scenarios (A1B and B1) described in Section 5. As implemented here, the delta method utilizes historic gridded daily precipitation and temperature for the period 1970-1999, produced using methods summarized in Maurer et al (2002), and adjusts these inputs based on projected mean monthly changes. Over the next year, hydrologic simulations will be performed using more sophisticated downscaling methods from 20 individual global climate models and two emissions scenarios for each model. Although the preliminary analysis cannot provide information as to the range of future impacts (which will result from the more detailed analysis), the delta method employed here should give a useful preview of average expected changes in the state's hydrology, based on the suite of 20 climate models.

As regional temperatures increase, precipitation will increasingly fall as rain instead of snow in high to mid-elevation watersheds. Increased temperatures will also result in earlier spring snowmelt in these watersheds. Low elevation watersheds will be much less affected by these shifts, as a majority of the precipitation on them falls as rain and the impact of snow on runoff is less significant. April 1 snow water equivalent (SWE) illustrates these changes (Figure 6.1). Snowpack changes predicted by the A1B scenario are greater than for the B1 scenario because the A1B scenario assumes higher greenhouse gas emissions and later stabilization, and thus warmer temperatures, than the B1 scenario. As shown in Figure 6.1, SWE for the A1B scenario is projected to decrease approximately 28% statewide by the 2020s and 41% by the 2040s, compared with the 1970-1999 average. Results for the B1 scenario suggest a 26% reduction in SWE by the 2020s and 35% by the 2040s, again compared with the 1970-1999 average.

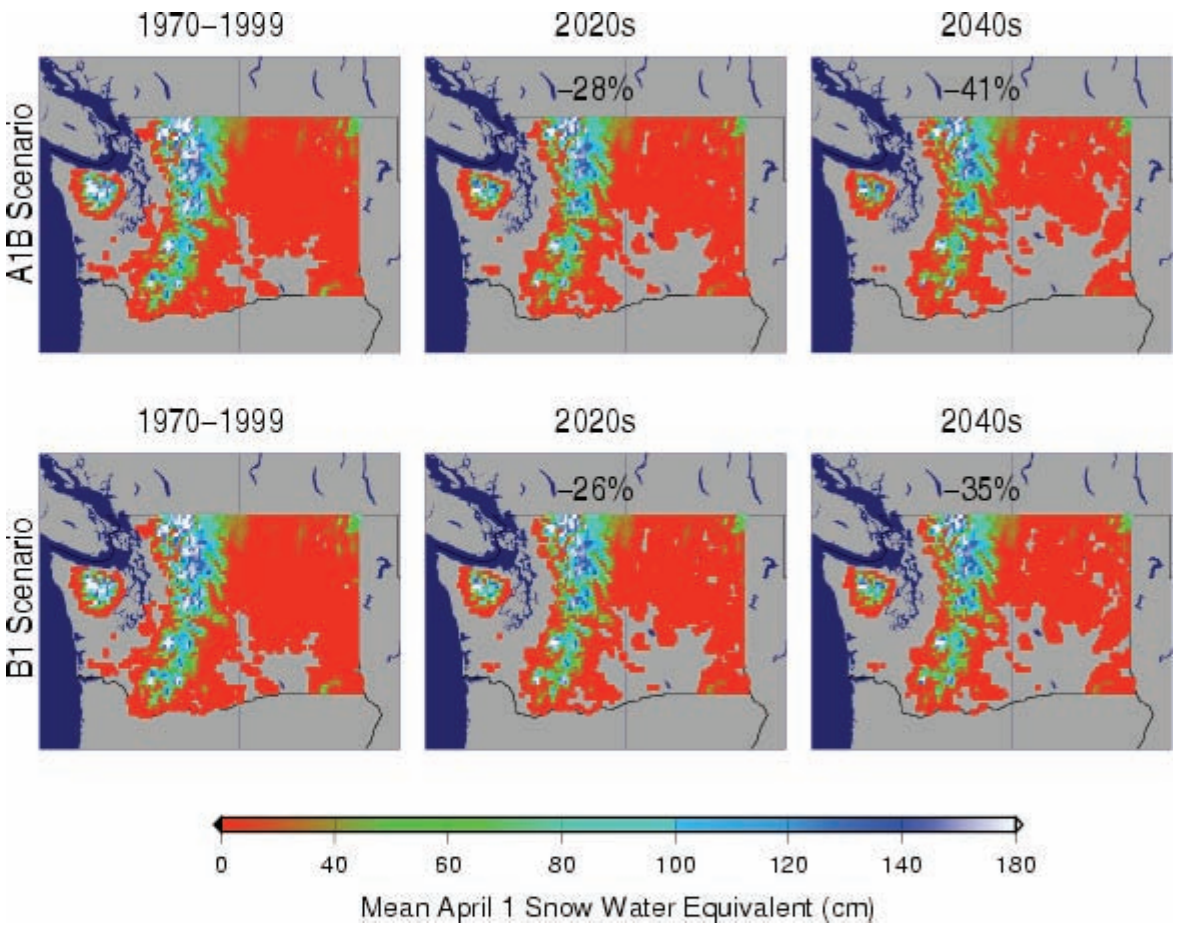


Figure 6.1. Mean 1970-1999 (left panels), projected 2020s (center) and 2040s (right) simulated April 1 SWE in centimeters, using two emissions scenarios A1B (top) and B1 (bottom). 2.5cm is approximately equal to one inch.

Increases in temperature, particularly during the summer months, will result in decreased soil moisture in the arid regions of the State. July 1 soil moisture (expressed as the depth of the top 0.4 meters (15.7 inches) of soil) is expected to decrease by an average of approximately 2.8-6.5% based on results from the two emissions scenarios (Figure 6.a.2). Changes in soil moisture will vary across the state. Mountainous regions will have 80% or less of historical average soil moisture, while arid regions of the state will have 90-95% of historical soil moisture.

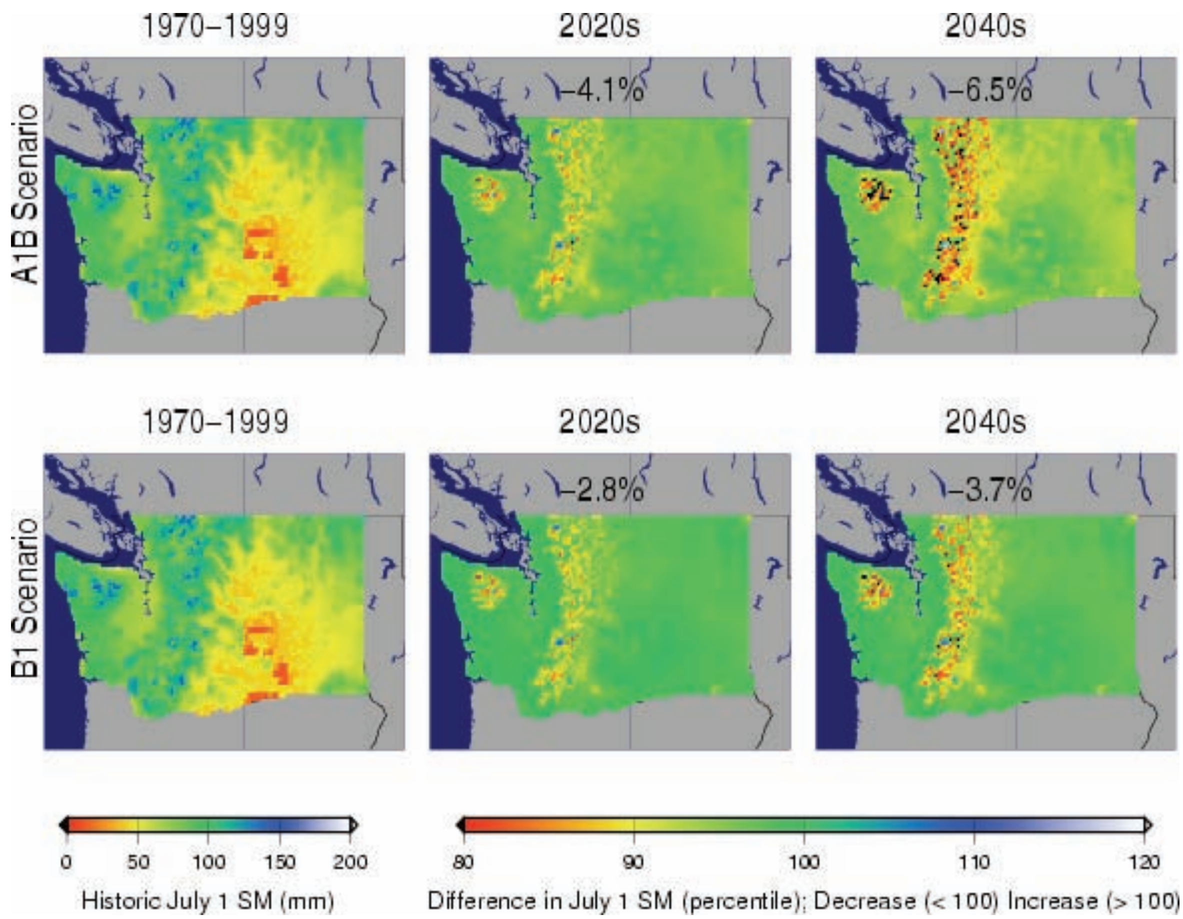


Figure 6.2. Mean 1970-1999 (left panels), projected 2020s (center) and 2040s (right) simulated July 1 soil moisture (to a depth of 0.4 meters, or 15.7 inches), using two emissions scenarios A1B (top) and B1 (bottom). 25.4 mm approximately equal one inch.

In addition to the preliminary statewide results, the same delta method downscaling approach was used to evaluate potential impacts of climate change on streamflow in the Snohomish River for the A1B scenario (Figure 6.3). Under average climatic conditions from 1970-1999, Snohomish River streamflow on average has a double peak – one in the winter, corresponding to low elevation winter rainfall, and a second in spring, corresponding to higher elevation snowmelt. A1B 2020s streamflow is slightly higher in autumn, winter and early spring, and lower in late spring and summer, compared to historic conditions (1970-1999). The slight projected 2020s changes are progressive through the century, until by the 2080s the winter rainfall-related peak dominates the seasonal cycle, and much of the spring peak is gone. As in many previous studies (Hamlet et al., in review; Hamlet and Lettenmaier 2007; Lettenmaier et al. 2005; Steinemann 2006), these projected changes are mostly attributable to projected temperature changes, which result in less precipitation falling as snow at high elevation, and earlier melt of the snowpack that remains.

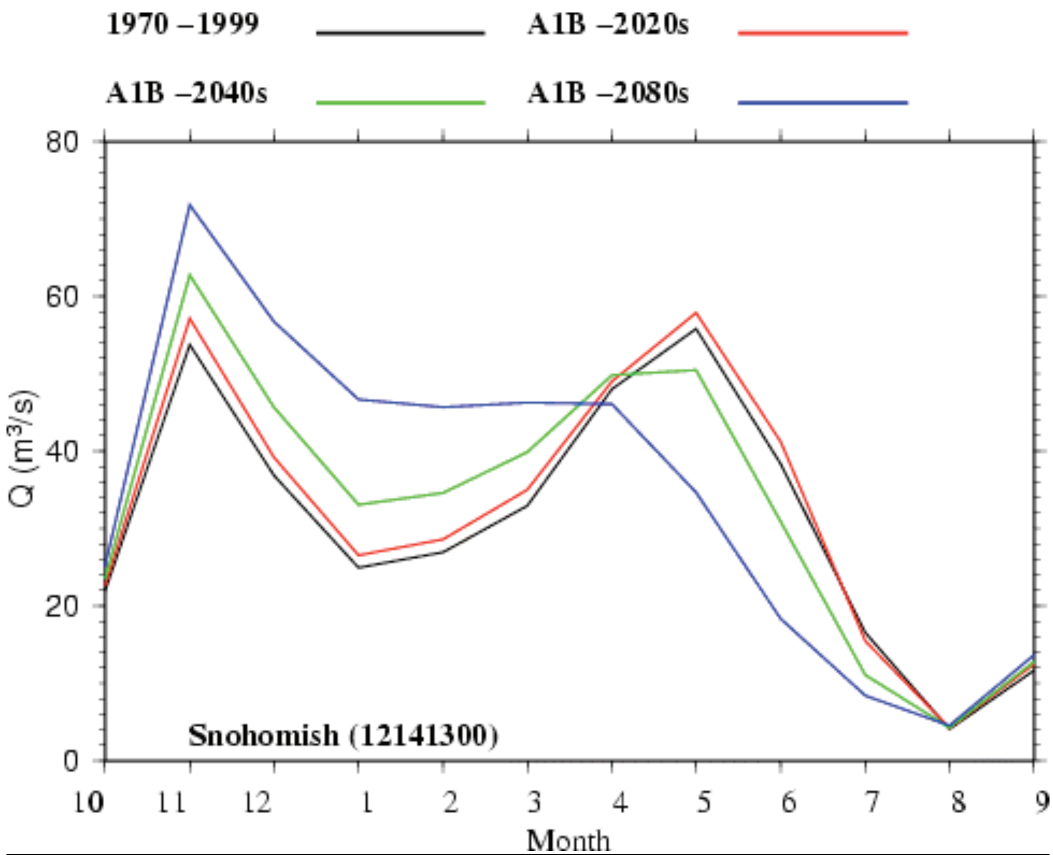


Figure 6.3. Impacts of climate change on streamflow in the Snohomish River. 1 cubic meter per second approximately equals 35 cubic feet per second.

Based on the work performed to date, our preliminary findings are:

a) The state's snowpack will, on average, be reduced through the next century, with mean changes associated with the average of the AR4 scenarios ranging from 28 to 41% for the 2020s to 2040s for A1B emissions, and 26 to 35% for B1.

b) Changes in summer soil moisture will be associated both with changes in temperature, leading to increased evaporative demand, and reduced summer precipitation, the result of which will be overall decreased soil moisture in both mountainous and arid regions, with some increases at highest elevations.

c) Projected changes in climate for the 2020s under the A1B scenario show streamflows are slightly higher in autumn, winter and early spring, and lower in late spring and summer, compared to historic conditions (1970-1999 and these changes persist through the century, until by the 2080s the winter rainfall-related peak dominates the seasonal cycle, and much of the spring peak is gone.

iv. Sensitivity to Climate Change and Potential for Adaptation

The water resources of the State of Washington are highly sensitive to climate change – especially to changes in the seasonal timing of streamflow. This is the case because the state's reservoirs are mostly small relative to the mean annual flow. For instance, storage in the City of Seattle's Tolt and Cedar River reservoirs is less than 14% percent of the combined flow of these two rivers. Therefore, management of the state's water resources is critically dependent on natural storage in headwater snowpacks, which the reservoir system essentially supplements. Increased temperatures and changes in precipitation will continue to alter the timing of seasonal flow in our rivers and streams, trends which are already underway (Stewart et al 2005). The regions of highest sensitivity will likely be transient watersheds that currently receive precipitation as a mixture of rain and snow because precipitation will increasingly fall as rain instead of snow. High elevation watersheds will be somewhat less sensitive, at least over the next few decades, although they will experience some transition of snow to rain, and hence experience reduced snowpack and earlier spring snowmelt. Low elevation watersheds, whose runoff is dominated by rainfall in the current climate, will be least sensitive. The highest potential for adaptation is likely to be in the area of reservoir management for hydropower, flood control, and water supply where changes in operations may be possible to compensate to some extent for loss of snowpack.

v. Interactions with Water PAWG

CIG's water sector has been working closely with the water resources/water quality PAWG. CIG has provided baseline information on past and projected climate change and the impact it continues to have on water resources. This information includes impacts on hydrology (including snowpack, streamflow, and extreme events) as well as water supply, energy, and stream temperature. The CIG has also collaborated with the PAWG leads on the recommendation-making process as well as the drafting of the PAWG recommendations.

b. Agriculture and Irrigated Agriculture/Economics

i. Management/Decision Context and Research Needs

The potential impacts of climate change on the state's agriculture will vary across crop types, and dry land and irrigated agriculture in ways that are not yet well known. One example of the direct effects of climate (temperature and moisture changes) on pests is the codling moth. A codling moth model has been developed to help growers time insecticide applications during the growing season against the first and second generation of this pest. Additionally, the model can predict the percent of third generation egg hatch (likely to increase with warmer temperatures), providing growers an indication of late season risk of crop damage. More detailed information on patterns of changes in daily temperatures is under development, which will provide the basis for more detailed analyses of their impact on tree fruit pests. Ongoing evaluation of pest management tactics under changed climate conditions will enable identification of effective management strategies for future cropping systems. This analysis will also provide a basis for predicting new weed, disease and insect species that may become important with changing climate as well as measures that may be required to manage these pests economically.

In the case of irrigated agriculture, the management / decision context of climate impacts is complicated by previous actions, requirements, and restrictions under Washington water law, as well as environmental requirements for in-stream water quantity and quality under federal and state environmental regulations. The impacts of climate change on irrigated agriculture follow two primary pathways. The first is direct climatic influence on crop physiological processes such as photosynthesis and respiration, which in turn affects the demand for irrigation water. The second is indirect climatic influence on hydrological variables that in turn impact water availability in specific basins. The impacts are inherently regional, based on the specific circumstances in each basin.

ii. Main Research Questions Addressed under HB1303

The overarching research question to be addressed by this sector is: *What will be the impacts of climate change on productivity and sustainability of the state's agriculture?*

The complexity and magnitude of Washington's agricultural sector is such that for this project, we are examining only key facets of the state's agricultural enterprises. These facets include climate change effects on:

- *tree fruits*
- *potatoes*
- *grapes*
- *dryland cropping systems*
- *weeds*
- *diseases*
- *insect pests*
- *agricultural economics*

Computer simulations, expert opinions, and experience from areas of the world with similar conditions to those predicted for climate change in WA are being used to assess the impact on cropping systems derived from changes in a) temperature, b) growing season length, c) precipitation patterns, d) water supply and demand, e) atmospheric CO_2, f) potential growth rate, and g) incidence of weeds, pests, and diseases. Climate change impacts on agriculture at the enterprise budget level will then be developed. These impacts include changes in pesticide use, expected yields, variability of yields, and entire shifts in crop production. When necessary, updated crop production budgets will be created to use as baseline budgets. After determining impacts at the farm level, these impacts will be extrapolated to the region and finally to the state. The potential for adaptation to expected climate change will be assessed.

iii. Scientific Progress and Key Findings

As noted above, evaluation of the impacts of climate change on irrigated agriculture based on the suite of 20 models and 2 emissions scenarios is underway; however results are not yet available. Therefore, preliminary findings are based on our past work, and literature review. Evaluation of the impacts of 2°C (3.6°F) of warming on the value of irrigated crops produced in the Yakima basin is presented below (Figure 6.4). The projected average annual temperature increase for the 2040s, considering both the A1B and B1 emissions scenarios, is approximately 2°C (3.6°F) (refer to Table 5.1). This analysis should give a useful preview of average expected impacts on irrigated agriculture, with more detailed analyses to be completed over the next year.

For irrigated crops, pesticide use will likely increase, particularly for apples and other tree fruits. Furthermore, warmer summer and fall temperatures will hasten ripening and affect fruit quality parameters such as flavor and color. Yields and quality of some crops (notably potatoes) will tend to decrease with increasing temperature, but much of the decrease may be offset (by higher atmospheric CO_2 concentrations) if additional irrigation water is available. However, the average total water supply available to irrigated agriculture in some eastern Washington irrigated areas (such as the Yakima basin) is likely to decline significantly under climate change, resulting in more frequent and more stringent prorationing of water to holders of junior water rights, and resulting decreases in crop production (see Figure 6.4). Furthermore, increased incidence of disease could result in decreased production – ranging from 10 – 50% in the case of potatoes under current cropping practices.

For dryland agriculture, climate change will force agricultural practices to adapt to longer growing seasons, and reduced summer precipitation. Weeds will likely be more competitive for nutrients and water in a warmer and elevated CO_2 environment and mild winter temperatures may enhance survival of some annual weeds.

Diseases will generally become more problematic over the next century, especially as a result of warmer temperatures. For instance, cherry and grape powdery mildew and fire blight are expected to increase in severity, although hop powdery mildew should not change. Some diseases that are not now economically important will become important and some exotic diseases will move into the region. Increased temperatures may result in earlier emergence (5 to 10 days) of codling moth adults in the spring. This earlier spring emergence coupled with warmer temperatures in summer may result in many locations experiencing a complete third generation egg hatch.

Based on the work performed to date, our preliminary findings may be summarized as:

a) The average total water supply available to irrigated agriculture in some eastern Washington irrigated areas (such as the Yakima basin) is likely to decline significantly under climate change, resulting in more frequent and more stringent prorationing of water to holders of junior water rights, and resulting decreases in crop production.
b) For dryland agriculture, climate change will force agricultural practices to adapt to longer growing seasons, reduced summer precipitation, and increasingly competitive weeds.
c) Diseases will generally become more problematic over the next century, especially as a result of warmer temperatures.

iv. Sensitivity to Climate Change and Potential for Adaptation

The potential for adaptation varies strongly across crop type, and irrigated versus dryland crops. For tree fruits, the current mix will shift. Cultivars that are better adapted to warmer temperatures can (and likely will) be planted, but establishment costs in tree fruits are substantial and will impose a large burden on the tree fruit industry. Potatoes are sensitive to climate due to the relatively low temperature required for tuber initiation and the crop's susceptibility to diseases and other pests. It is possible to offset some of the deleterious effects of warmer early-season temperatures by selection of new cultivars, earlier planting times, or moving the farm to a more favorable location. Grape and wine production is highly sensitive to climate variability. The current climate of Washington State is nearly ideal for premium-quality wine grapes. Therefore, shifts in the variety makeup of different regions within the state and the decrease of suitable areas can be expected. With respect to dryland agriculture, marginal production areas on the warm, dry end of the climate spectrum may not support agriculture under climate change scenarios. With respect to weeds, insects and diseases, all are highly adaptable, and are therefore sensitive, at least in some life cycle stage, to changes in climate. Adaptation to changes in incidence and severity of these pests will require prediction of which pests may move into the region, and which endemic pests may become more problematic.

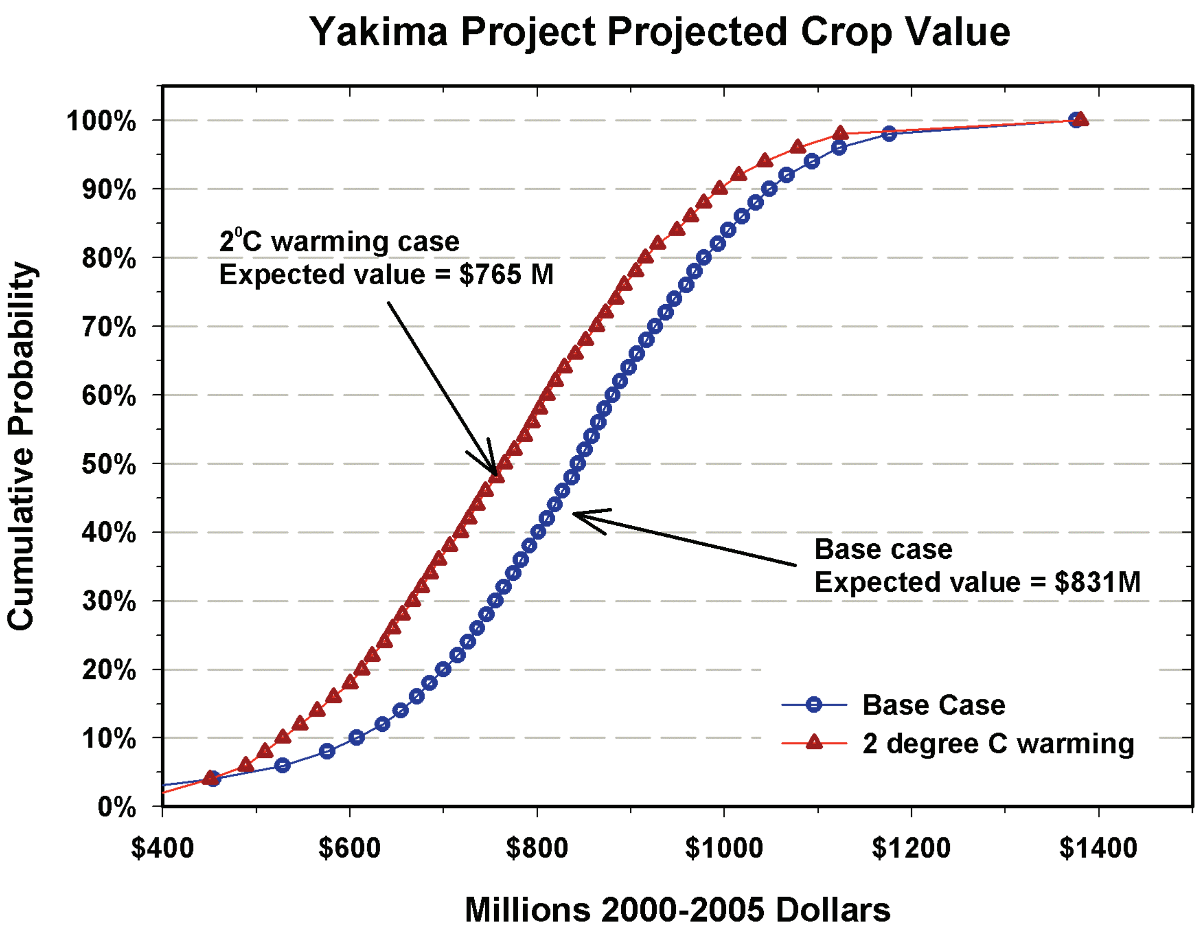


Figure 6.4. The cumulative distribution of the value of irrigated crops produced in the Yakima Basin with base climate and 2ºC (3.6°F) climate warming, with no planned adaptation.

v. Interactions with Agriculture PAWG

The CIG HB1303 agriculture sector is interacting with the Agriculture PAWG in two areas. The first is water issues related to agriculture. We have provided preliminary results of modeling work for the Yakima basin (Figure 6.4), which illustrate the implications of changing water supply on agricultural production and help to provide a technical basis for the Agriculture PAWG recommendations. The second area of interaction is the PAWG evaluation of issues related to insect and disease pests. In this area, CIG is supporting the PAWG with our understanding of the susceptibility of Washington crops as summarized above. The final CIG HB 1303 report will address these pests as well as weeds. In contrast to the PAWG effort, our work will provide an assessment of the responses of broad agricultural sectors to climate change, rather than individual crops.

c. Salmon

i. Management/Decision Context and Research Needs

The impacts of climate change on freshwater salmon habitat follow two primary pathways. The first is direct climatic influence on hydrologic processes that influence the volume and timing of stream flow and stream temperature. The second is via the indirect climatic influences on the human use of water resources that in turn impact the same hydrologic parameters influencing stream flow and temperature. Key factors that influence the sensitivity of freshwater salmon habitat to climate change include: watershed geomorphology, vegetative cover, the relative importance of ground-water hydrology in the stream reach of interest, water resources infrastructure (dams and diversions), the amount and timing of stream flow diverted to out of stream uses, and the degree to which key hydrologic processes have been impaired by changes in watersheds. The management/decision context for these changes is complicated by the patchwork of ownerships with different mandates (federal, state, county, municipal, irrigation districts, and private land owners), which nonetheless are all are subject to a common set of regulations protecting water quality. The Environmental Protection Agency (EPA) and Washington State Department of Ecology are the primary regulatory agencies charged with protecting water quality, while the Washington Department of Fish and Wildlife has hydraulic permitting authority to protect freshwater habitat for fish and wildlife.

ii. Main Research Questions Addressed under HB1303

The overarching question to be address by this sector is*: How will climate change alter the potential productivity of the state's streams for salmonids, and where and under what conditions is salmonid habitat most vulnerable to direct (rising water temperatures and altered flow) and indirect (habitat) effects of climate change?*

Subsidiary questions include:

a) What will be the role of climate variability and change in coming decades on summertime stream temperatures?
b) What will be the effects on summer low flows and flood peaks of climate change?
c) How will these hydrologic changes affect the freshwater productive capacity for salmon?

iii. Scientific Progress and Key Findings

We are using three approaches to address the key research questions. Statistical models are being developed to relate surface air temperatures to stream temperatures. Hydrologic modeling, which is being carried out in cooperation with the water sector, will provide scenarios for changes in summer low flows and flood peaks. A review and synthesis of published scientific literature will guide our assessment of how projected changes in stream flows and hydrology will affect the freshwater productive capacity for salmon. Although the hydrologic modeling work is underway, results based on the suite of individual GCMs are not yet available, and our preliminary findings are therefore taken from a combination of synthesis of prior literature and preliminary work using a delta method approach on stream temperature data assembled for HB1303.

Key limiting factors for freshwater salmon productivity will depend on species, their life history, and watershed characteristics, however increasing summertime stream temperatures are likely to be a key pressure point for many salmon populations. As shown in Figure 6.5, many stream reaches in Washington have water temperatures that exceed water quality standards, and the incidence of violations, especially in summer, will increase with warmer summer temperatures and reduced low flows due to earlier snowmelt. In the 2001-2006 period, 15% of the stations included in our analysis had an observed maximum weekly average water temperature greater than the 21ºC (70°F) water quality criteria, and all of those stations are located in the interior Columbia Basin. Under the A1B emissions scenario, 2040s August average air temperatures are projected to rise by 2.8ºC (approximately 5.0°F). Using the delta method by assuming an equivalent rise in the annual maximum weekly water temperature results in 49% of these stations exceeding the 21ºC (70°F) criteria, with many recording stations in southwest Washington and the Puget Sound Lowlands and all the stations in the Columbia Basin exceeding the 21ºC (70°F) criteria. Although this approach ignores a range of factors that give rise to the observed heterogeneity in stream temperatures, this simple projection should give a useful preview of the projected stream temperatures we will develop in the next year using the 1/16 degree gridded air temperature fields and empirically-based stream temperature models.

Changes in runoff patterns and extremes will be in part determined by watershed type. Hamlet (2006) shows that systematic shifts in temperature associated with climate change cause different patterns of changes in flooding. Washington's warmer (mostly westside), transient snowmelt/rainfall basins are projected to experience increased flooding in fall and winter with more rain on snow events and rising snowlines, while Washington's colder (mostly eastside) snowmelt dominated basins are projected to experience reduced springtime snowmelt flooding as the total snowpack declines. Fall and winter flooding is known to be a limiting factor for some Washington salmon populations because extremely high flows can scours redds, lead to sediment deposition that suffocates incubating eggs, or flush rearing fry and parr downstream to unfavorable habitat. Because of the advanced timing of snowmelt and increased evaporation, most of Washington's river basins are projected to experience reduced stream flow in summer and early fall. In combination with increased summertime stream temperatures, reduced summertime flow is likely to limit rearing habitat for salmon with stream-type life histories (wherein juveniles rear in freshwater for 1 or more years) and increase mortality rates during spawning migrations for summer-run adults. In the next year we will be using the spatially-explicit projected flow changes to develop GIS layers indicating changes in hydrologic limiting factors, and how those changes are likely to impact different salmon species and life history types.

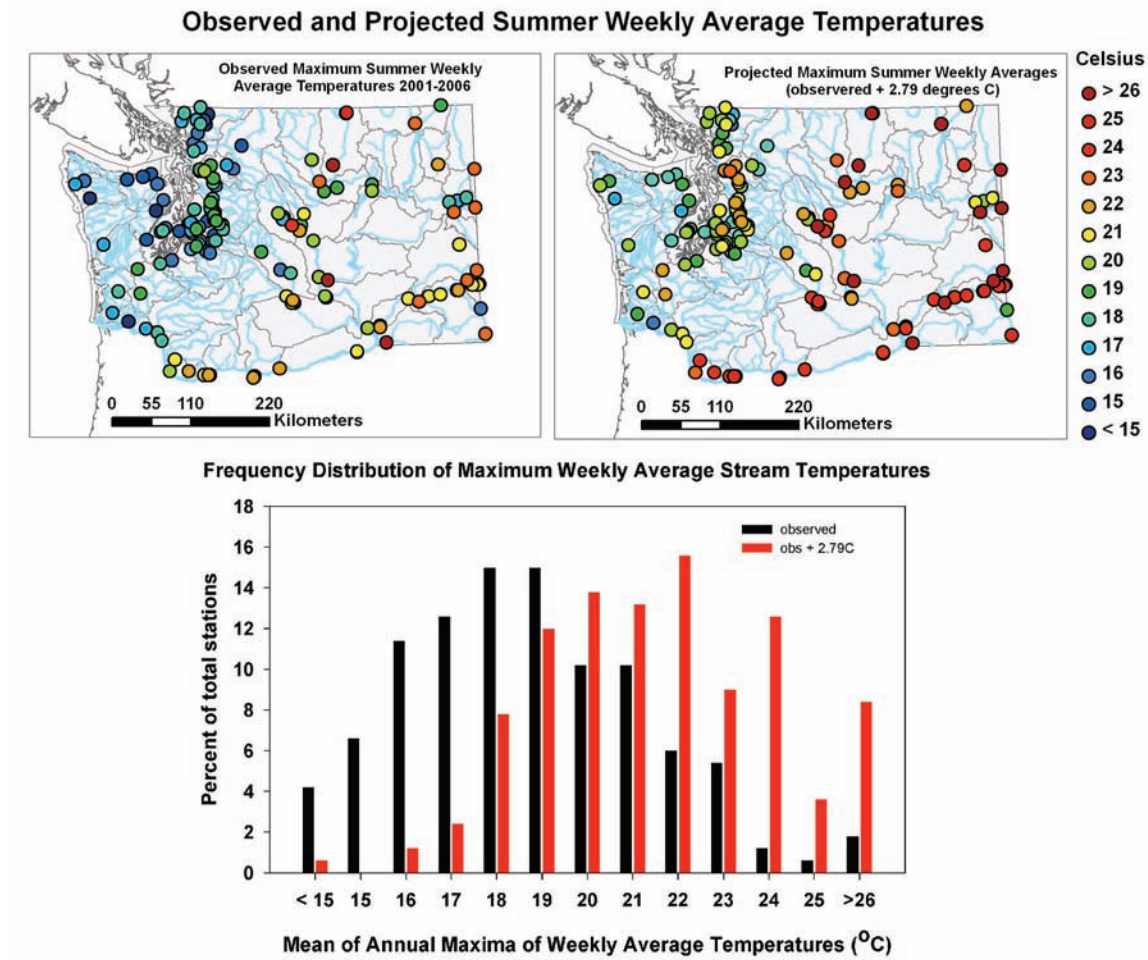


Figure 6.5. Top panel: (left) Observed average of the maximum weekly average water temperatures for the 2001-2006 period; (right) Projected average of the maximum weekly average water temperatures using a simplified "delta-method" approach with the temperatures shown in the left panel increased by 2.8°C, or 5.0°F (the multi-model composite statewide warming in August projected for the 2040s under the A1B emissions scenario). Bottom Panel: Frequency distributions for the average maximum weekly average stream temperatures for the 2001-2006 period (black) and for a 2.8°C, or 5.0°F, warming scenario (red).

Based on the work performed to date, our preliminary findings are:

a) In the 2001-2006 period, 15% of the stations included in our analysis had an observed maximum weekly average water temperature greater than the 21ºC

(70°F) water quality criteria, and all of those stations are located in the interior Columbia Basin.

b) Under a delta method analysis of the A1B emissions scenario, 49% of these stations are projected to exceed the 21ºC (70°F) criteria by the 2040s, including many recording stations in southwest Washington and the Puget Sound Lowlands and all the stations in the Columbia Basin. This preliminary projection highlights increased stress on salmon populations that use these watersheds in the warmest summer months.

c) Regional warming will result in reduced springtime snowmelt flooding in snowmelt dominant (mostly eastside) watersheds, and increased fall and winter flooding (including rain on snow events) for warmer (mostly westside) watersheds. The latter will likely reduce egg-to-fry and overwinter survival rates for some fall spawning salmon populations. In contrast, warmer stream temperatures and reduced late-summer-to-early-fall flows are projected for watersheds statewide, and this combination will likely stress salmon populations that utilize freshwater habitat in the warm summer months (adults on their spawning migrations and rearing juveniles).

iv. Sensitivity to Climate Change and Potential for Adaptation

The hydrologic processes that influence stream flow timing, volume, and stream temperature are highly sensitive to climate variations. Reducing existing threats to freshwater habitat for salmon caused by land and water use actions that impair natural hydrologic processes provides avenues for mitigating future climate change impacts. Potential adaptation options for mitigating stream temperature increases in response to climate change include reduced out of stream withdrawals during periods of high temperature and low flow, identifying and protecting thermal refugia provided by ground-water inflows and deep stratified pools, and restoring riparian zones. Protecting and/or restoring instream flows in summer is also a key adaptation option. Adaptation strategies for reducing the risk posed to salmon habitat by extremely high flow events in fall in winter include protecting and restoring off-channel habitat in floodplains. In watersheds with large storage reservoirs there may be opportunities to change reservoir operating rules in ways that mitigate water temperature and low flow changes by augmenting water released from reservoirs at key times.

v. Interaction with Water PAWG

The CIG HB1303 salmon sector does not have a parallel salmon PAWG with which to collaborate on recommendations for adaptation to climate change (refer to Figure 4.1). However, due to the obvious connection between salmon and water resources, issues surrounding the impact of climate change on anadromous and resident fish were considered by the Water PAWG and the Forest PAWG.

d. Forests

i. Management/Decision Context and Research Needs

The affects of climate change on forest ecosystems are both direct and indirect. Climate directly influences tree physiological processes such as photosynthesis and respiration, and indirectly influences hydrological variables that control tree growth (e.g., soil moisture limitations), the biophysical environment (e.g., fuel moisture), and disturbance (principally fire and insect outbreaks). Most other effects, e.g., on habitat for forest-dependent species or watershed productivity, follow from these. Adaptation to climate impacts on Washington's forests ecosystems must take place within a management and policy context that is complicated by the patchwork of ownerships with different mandates and regulations (federal, state, corporate, and private forests).

ii. Main Research Questions Addressed under HB1303

The overarching research question being addressed by the CIG HB1303 forest sector is: *What will be the effects of climate change on the growth and productivity of forests and their susceptibility to fire and insect disturbance?*

Subsidiary science questions are:

a) How will climate change affect fire regimes?
b) How will climate change affect insect outbreaks in Washington's forests?
c) How will climate change affect tree species distributions?
d) How will climate change affect forest productivity?

iii. Scientific Progress and Key Findings

Interim research findings are based on a combination of synthesis of existing literature and preliminary work assessing climate scenarios and variables (e.g., soil moisture) derived by the hydrology sector. Our preliminary findings are presented below.

The forested area burned by fire in Washington is strongly related to climate. This relationship is expected to continue, particularly the influence of summer drought (low precipitation and warmer temperatures between May and September). These relationships exist in both the historical (pre-1900) and contemporary record, and are particularly strong since 1977. Without an increase in summer precipitation (greater than any predicted by climate models), future area burned is very likely to increase. Forests east of the Cascade crest will be most susceptible to larger and more severe fires in a changing climate.

Although other insect populations may increase with warmer temperatures, the mountain pine beetle poses the greatest threat of damage to Washington forests over the next several decades because it responds directly to warmer temperatures. In the past, high stand densities rendered forests susceptible to beetle outbreaks, but since roughly 2000, warming temperatures have been more closely associated with outbreaks. Eastside forests dominated by lodgepole pine and possibly ponderosa pine, both host species for the beetle, will be most susceptible in a changing climate.

The distributions of many tree species are controlled by energy-related variables (e.g., temperature, solar radiation, soil temperature), water-related variables (precipitation, snowpack, soil moisture), or both. Relatively small changes in these variables (e.g., increased temperature) could produce shifts in species ranges and changes in dominance within those ranges. Washington state forests most likely to experience major changes in composition in a changing climate will be those near the lower treeline on the east side (ponderosa pine and Douglas-fir) and at the upper treeline on both sides of the Cascade Crest.

Warmer temperatures are likely to affect forest productivity statewide, especially of lower-elevation Douglas-fir. The growth of Douglas-fir is strongly related to both water availability and temperature; water balance deficit is a significant predictor of growth. The limiting factors for Douglas-fir growth may change from light availability (particularly westside lower elevations) and cold (upper elevations) to water-balance deficit over significant acreage in Washington. The most vulnerable part of the state will initially be montane Douglas-fir stands on the east side, but eventually the more productive commercial forests of the west side.

Key findings may be summarized as:

a) Wildfires are strongly associated with climate, especially in eastside forests.
b) Mountain pine beetle poses a significant threat to Washington's pine forests.
c) Tree species composition will change as species respond uniquely to a changing climate.
d) Productivity of Douglas-fir forests is likely to decrease statewide.

iv. Sensitivity to Climate Change and Potential for Adaptation

Most key processes in forest ecosystems are sensitive to climate change. The highest sensitivity to the direct effects of climate will most likely be in forests that are currently at the edge of the forest distribution (particularly lower treeline). A biome-type shift, from forest to savanna or shrubland, is likely in these forests, particularly with the projected shift towards drier summers (refer to Section 5). The highest sensitivity to changing disturbance regimes is likely to be in east side pine-dominated forests, in which both increased fire extent and severity and increased insect outbreaks are expected. The highest potential for adaptation is likely to be in forests that are not yet at the transition from energy-limited to water-limited, because rapid species changes or declines in productivity will not be felt for a few decades.

v. Interactions with Forest Resources PAWG

The forest resources PAWG has identified adaptation issues in fire and forest health, species and physiological changes, timber management, and habitat that relate specifically to the CIG HB1303 Forest sector priorities. We are coordinating with the forest PAWG to provide information needs related to a) vulnerability thresholds for various species and ecological communities; b) carrying capacity of specific forest sites given changes in soil water balance; c) precipitation, runoff, and streamflow patterns in local watersheds, given specific climate change scenarios (being undertaken jointly with the CIG HB 1303 hydrology sector).

The Forest Resource PAWG has identified as their key objective:

> "Complete a <u>vulnerability assessment</u> to identify specific species, landscapes, and cultural resources that may be most sensitive to climate change. Consider especially the potentially changing patterns of major disturbance forces such as fire, wind, and flooding which may challenge past paradigms for protection. Identify locations which may be especially important nodes in movement patterns of species."

The CIG HB1303 forest sector will provide projections of landscape changes in species composition, forest productivity, fire extent and severity, and insect outbreaks, in support of this vulnerability assessment.

e. Coasts

i. Management/Decision Context and Research Needs

The manifestation of climate change on Washington State's coastal sector will be through direct and indirect effects of sea level rise. The resulting effects are complex in their bio-physical manifestations, social-economic aspects, and the need for individual and governmental adaptations. The coasts encompass the State's largest cities and ports, numerous small towns, extensive residential development, a variety of rural areas, large agricultural districts, marine sanctuaries, tribal property, as well as intertidal zones supporting shellfish aquaculture and providing nursery areas for marine organisms. The coastal regulatory context involves a variety of overlapping jurisdictions and all levels of government. In addition to sea levels rise, the coastal sector will be affected by increasing ocean temperature, ocean acidification, and coastal erosion, all of which will likely stress both social-ecological and the management and decision making aspects of the coastal zone.

ii. Main Research Questions Addressed under HB1303

The overarching research question being addressed by the coastal sector is: *To what extent will rising sea levels and ocean temperatures impact the coasts, estuaries, and harbors of the state through inundation, increased flooding, and/or erosion?*

Subsidiary science questions include:

a) To what extent will rising sea levels, increasing ocean temperature, increasing flooding and/or erosion impact coastal areas?
b) How will these changes affect urban waterfronts, port areas, delta regions, residential communities, and the communities on the Pacific coast?
c) How will shellfish aquaculture be impacted?
d) What response opportunities or constraints are imposed by the current legal and regulatory framework?
e) How can the impacts of coastal climate change be reduced by adaptation efforts?

iii. Scientific Progress and Key Findings

Interim findings of the coastal sector are based on a combination of results from prior studies and a preliminary sea level rise scenario developed by the Scenarios Working Group. GIS based mapping of "Medium" (2-feet, or 0.6m, of rise by 2100) and "Very High" (4-feet, or 1.2m, of rise by 2100) sea level rise scenarios, as discussed in Section 4, and changes to the associated coastal flood plain are shown below for four selected areas. Classifications of areas likely to be the most vulnerable to the effects of sea level rise have been identified, but not specific geographic locations.

a) **b)**

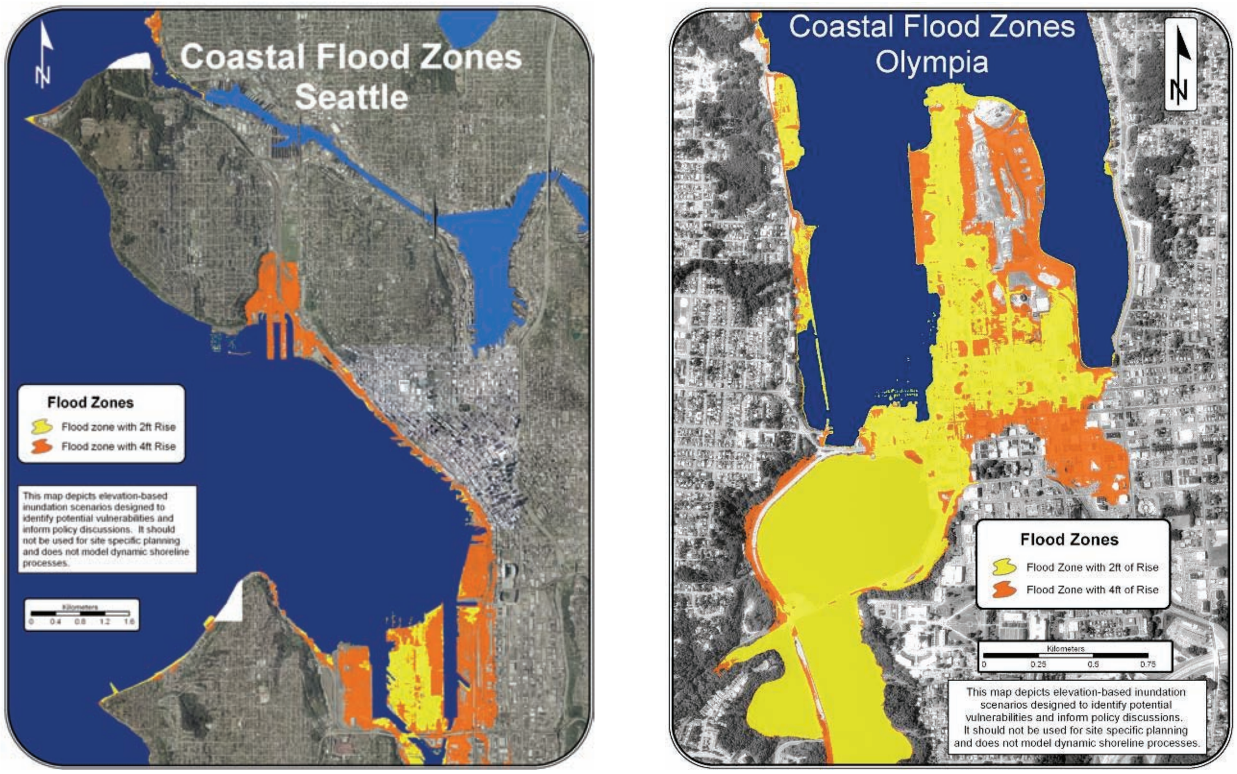
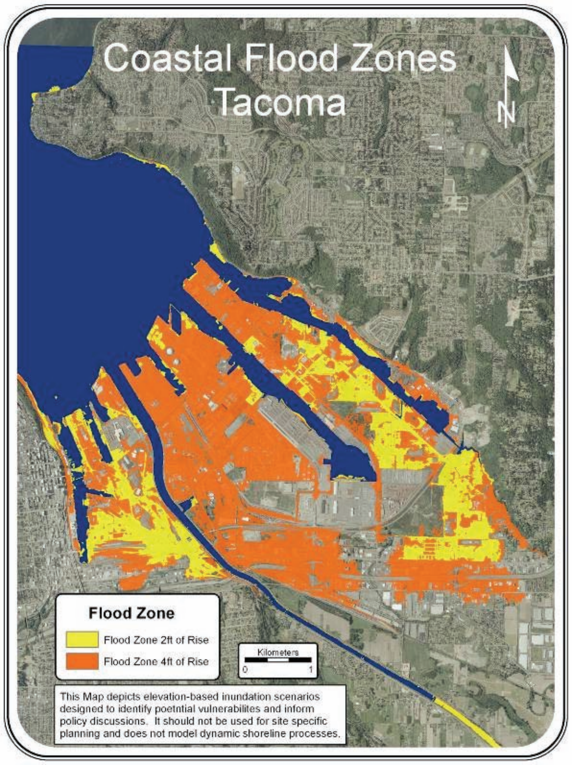


Figure 6.6. Maps of coastal flood zones with sea level rise for: a) Seattle, b) Olympia with predicted flood zones for "medium" (2-feet, or 0.6m, of rise by 2100, yellow) and "very high" (4-feet, or 1.2m, of rise by 2100, orange) sea level rise estimates. Maps are based on current coastal zone elevations and do not include potential human adaptation responses such as protection of coastal property.

The downtown waterfront areas of both Seattle and Olympia show substantial inundation during episodic flood events for the selected sea level rise scenarios (Figure 6.6). Both Harbor Island in Seattle and Olympia's port peninsula are built on fill at low elevations and are vulnerable to substantial flooding under the lower 2 ft (0.6 m) sea level rise scenario. Some critical facilities, such as the West Point sewage treatment facility in Seattle as well as the Cascade Pole hazardous waste site and LOTT (Lacey, Olympia, Tumwater, Thurston) Partnership sewage treatment plant in Olympia, are above the coastal flood plain, but may be at risk from storm surge and wind driven waves.

a)



b)

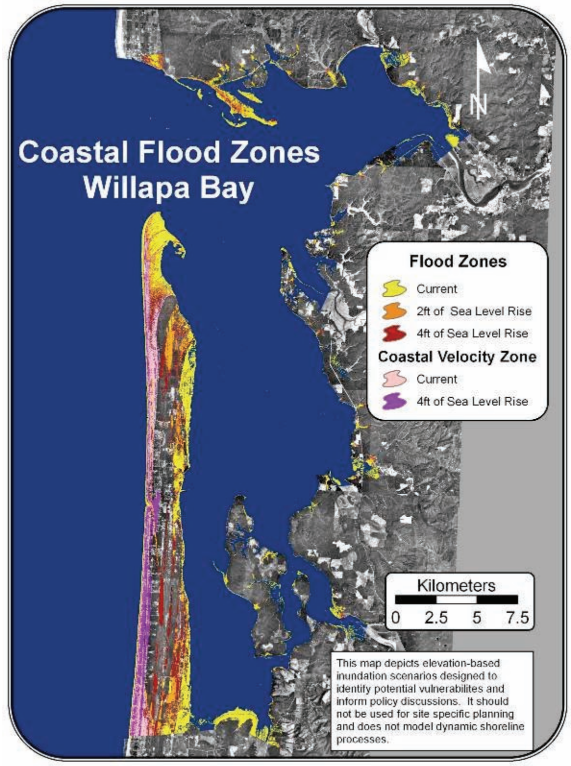


Figure 6.7. Maps of coastal flood zones with sea level rise for a) Tacoma, and b) Willapa Bay. Same as 4.5.1, but the map of Willapa Bay also includes the potential for higher flood elevations on the Pacific Coast based on wind driven waves and storms (purple).

Tacoma's port district is at risk and would lie almost entirely within the flood plain with the 4 ft (1.2 m) sea level rise scenario (Figure 6.7). The outer coast of the Long Beach Peninsula in Willapa Bay shows high levels of vulnerability based on the potential for storm surge and wind driven waves. For some areas, particularly the tip of the peninsula, flood events are likely to overtop the crest of the peninsula.

Based on work to date, our primary preliminary findings are:

a) GIS based mapping of inundation and flood events shows that episodic flooding will likely pose greater risks than inundation caused by sea level rise. Beach erosion and bluff landslides are also projected to increase.

b) Ecosystems are projected to experience significant changes, most importantly the loss of near-shore marine organisms and coastal habitats as these areas are squeezed between rising water levels and upland barriers. Increases in water temperature may facilitate expansion of disease and increase the range of invasive species. Pocket estuaries, spits, and nearshore habitats with heavily armored shorelines are likely to be the most susceptible.

c) Foresight and planning by public and private property owners, along with shoreline management policies that encourage adaptation, will determine the magnitude of economic impact to high value coastal property, public coastal infrastructure, and shellfish harvests.

d) Social vulnerability varies throughout the coastal zone and dependents on demographic factors such as: age, income, ethnicity, access to resources, and education. These factors influence a community's ability to adapt and coastal tribes, with their cultural connections to the landscape and place based treaty rights, face unique adaptation challenges.

iv. Sensitivity to Climate Change and Potential for Adaptation

The coastal sector's sensitivity to climate change is dependent on a number of local factors and can vary substantially between regions. Sea level rise and the associated coastal changes are projected to happen gradually over time. However, the coastal sector is particularly sensitive to low-frequency high-impact storm and erosion events that are difficult to predict. Highest sensitivities occur in heavily developed, low lying regions, or areas that do not have the resources to adapt to predicted changes. Private and public adaptations, through market adjustments and changes in zoning policies, have the potential to substantially decrease the long-term social-economic disruptions of climate change within the coastal sector.

v. Interactions with Coasts and Infrastructure PAWG

CIG's Coastal Sector has been working with the Coasts and Infrastructure PAWG. CIG has provided a baseline assessment of Washington State's coastal zone focusing on the Coasts and Infrastructure PAWG's general areas of interest. This baseline briefly describes estimates of future sea level rise and highlights how climate change will likely effect inundation, episodic flooding, salt water intrusion, erosion, and coastal habitat.

f. Infrastructure

i. Management/Decision Context and Research Needs

Infrastructure systems are among the most critical in modern societies, particularly for urban areas, and so even modest disruptions to them have significant impacts on daily life. A systematic shift in the frequency or intensity of those disruptions could have profound consequences for economic and human well-being.

Based on our initial studies of potential disruptions resulting from future climate change, critical impacts in the state of Washington will likely involve alterations to the hydrologic regime and their consequences for urban stormwater. We anticipate that projected increases in the frequency of larger, more intense storms may yield corresponding increases in property damage, disruption to transportation, wastewater system overloads in areas of combined sewers, and damage to aquatic ecosystems that are already the focus of great attention and substantial expenditures across the state.

ii. Main Research Questions Addressed under HB1303

The overarching research questions being addressed by the infrastructure sector is: *What are the most vulnerable elements of the state's civil infrastructure to climate change, and what adaptations can best reduce these impacts?*

The scope of the CIG HB1303 Infrastructure research is therefore focused on stormwater. The foci are:

a) What is the influence of climate change on the precipitation regime in Washington State?
b) What is the effect of these precipitation changes on critical stormwater facilities and flood-prone areas, particularly the conveyance capacity of existing infrastructure and the frequency of flood inundation?
c) What are the critical vulnerabilities of existing urban infrastructure to increased stormflow and failures of stormwater facilities?
d) What are the economic impacts of increased precipitation on stormwater-related damages?

iii. Scientific Progress and Key Findings

The main results of this research to date are taken from a combination of prior literature and preliminary work on data assembled for HB1303. First, global climate models predict that precipitation intensity will most likely increase in the Northwestern US over the next 50 years.

This general finding has been supported by numerous large scale studies, including previous work by CIG. However, this prediction remains provisional, pending further work being done by others as part of the overall HB1303 project. Second, municipal water utilities have generally not integrated climate change impacts into stormwater planning and drainage infrastructure. Though there is a general acceptance of the problem of climate change impacts and a desire to prepare for them, the integration of climate change impacts into planning and design standards is proceeding very slowly. Third, stormwater impacts and stormwater management already carry significant economic costs for municipalities throughout western Washington, as well as across the rest of the state. A sampling of these costs is presented in Table 6.1, for several municipalities, ranging in population size. It should be noted that the mean annual per-capita cost of stormwater expenditures was $88, with a range of $75 to $142. Also, the proportion of capital improvement costs represented by flooding and drainage issues is presented in Figure 6.8. On average, flooding and drainage represents 55% of the capital improvement costs for the eight jurisdictions listed in the figure. In summary, the key findings are:

a) Global climate models predict that precipitation intensity will most likely increase in the Northwestern US over the next 50 years.
b) Municipal water utilities have generally not integrated climate change impacts into stormwater planning and drainage infrastructure.
c) Stormwater impacts and stormwater management already carry significant economic costs for municipalities throughout western Washington, as well as across the rest of the state.

iv. Sensitivity to Climate Change and Potential for Adaptation

Typically, urban stormwater drainage infrastructure is designed to convey the runoff from a rainstorm of a specified duration (e.g., 24 hours) and return period (e.g., 25 years). If precipitation events of any given return frequency increase in intensity, duration, or both, then the runoff rate would likely increase as well. The economic impact of increasing the capacity of stormwater facilities or the disabling of key assets because of more severe flooding could both be high.

We anticipate high sensitivity to climate impacts will occur in those urban areas that already have poor stormwater drainage together with little undeveloped land on which to construct new (or expand existing) facilities. Adaptive capacity should be high where low-impact development (LID) drainage systems can be widely deployed to reduce the overall amount of stormwater entering the conveyance system.

Table 6.1. Examples of stormwater expenditures by various western Washington jurisdictions (from Visitacion et al., 2007a).

Jurisdiction	2006 Stormwater Expenditures[a]	2006 Expenditures/Capita[g]
Small (Population < 10,000)		
Town of Friday Harbor[b]	$284,000	$143
Medium (10,000 < Population < 100,000)		
Bellingham[c]	$4.8 million	$71
Bremerton[d]	$2.5 million	$67
Olympia[e]	$3.6 million	$84
Large (Population > 100,000)		
Seattle[f]	$42 million	$75

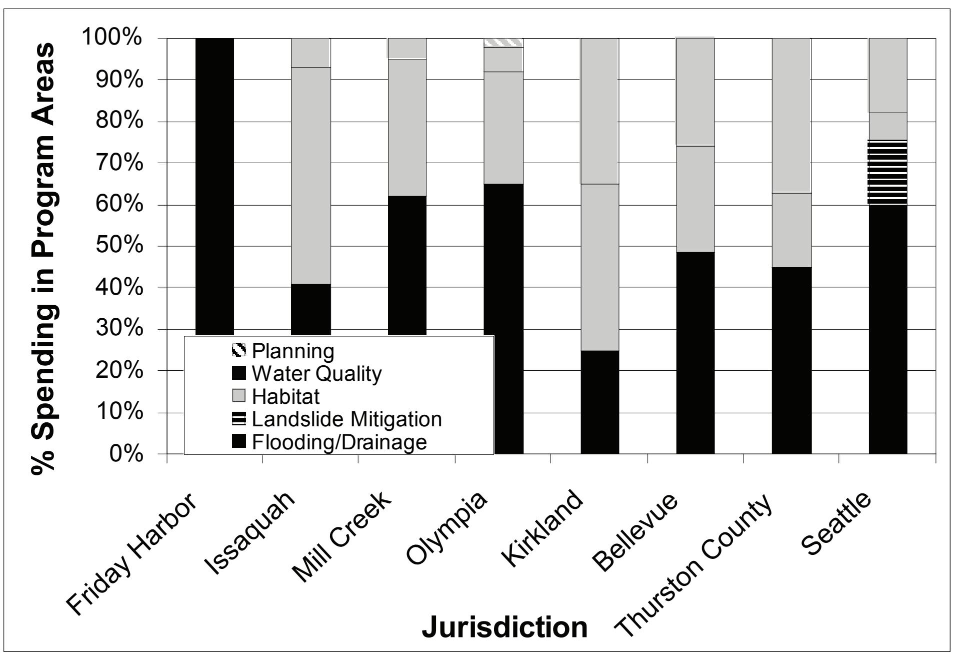


Figure 6.8. The total capital improvement project costs of jurisdictions in the Puget Sound region, in order of increasing population, are as follows, represented in 2006 dollar values (from Visitacion et al., 2007b).

g. Energy

i. Management/Decision Context and Research Needs

Climate has a number of direct and indirect effects on energy supply and demand in the Pacific Northwest that are of importance to Washington State. Direct effects include changes in energy demand associated with temperature (related, for example, to residential space heating), and changes in the seasonality and annual amount of hydropower related to changes in streamflow timing or annual volume. Some potential indirect effects include changes in hydropower production related to climate change adaptation for other water management objectives (e.g., attempts to adapt to losses of instream flow in summer), climate related effects to fossil fuel costs or availability, climate related effects to renewable energy resources such as wind turbines or photovoltaic cells, and shifts in population that may be partly related to changes in climate or water supply.

ii. Main Research Questions Addressed under HB1303

The overarching research question being addressed by the coastal sector is *How will the state's hydropower generating resources and energy demand be affected by climate change?*

Subsidiary research questions include:

a) What are the direct impacts of temperature change on heating and cooling degree days?
b) What are the impacts of heat island effects and projections of changing population on energy demand in urban/suburban population centers?
c) How will changes in annual streamflow volume and timing affect Columbia River hydropower production?

The scope of the CIG HB1303 project with respect to energy resources is to evaluate the impacts of climate change on energy demand across WA State using grid-based approaches, and to provide a preliminary estimate of changes hydropower production from the Columbia River Hydropower system.

iii. Scientific Progress and Key Findings

Preliminary impacts of climate change on Washington State heating and cooling degree days were determined using mean projected changes in temperature for the 2020s and 2040s for the A1B emissions scenario. Similar to analyses performed by other sectors, a delta method approach was used to estimate these impacts. In this approach, time series of historic temperature were adjusted by the projected mean changes for simulations of mean hydrology for these periods over the State. Results of this analysis provide mean projected changes in heating and cooling degree days across the State.

In 2008, the additional effects of heat islands and estimated population changes on energy demand will be estimated for a wider range of scenarios. Data over specific population centers will also be produced.

Key findings based on the preliminary estimates of mean annual heating degree days (Figure 6.9) and cooling degree days (Figure 6.10) are presented below. Heating degree days are the

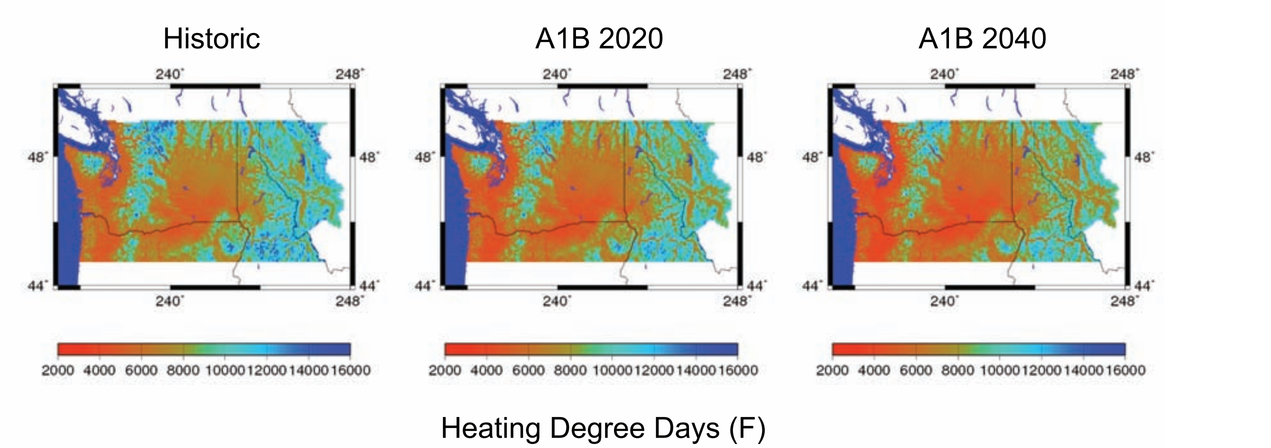


Figure 6.9. Estimated heating degree days (Farenheit) based on the period 1970-1999. (Heating degree days are calculated based on a threshold of 65°F, or 18°C).

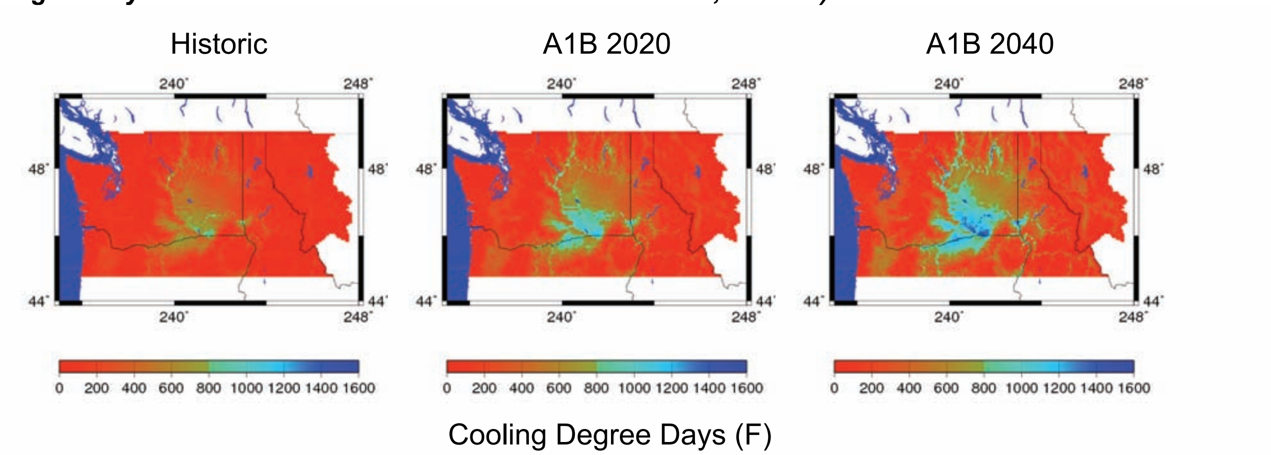


Figure 6.10. Estimated cooling degree days (Farenheit) based on the period 1970-1999. (Cooling degree days are calculated based on a threshold of 75°F, or 24°C).

dominant energy-related factor for WA in both the late 20th century climate and future scenarios, but cooling degree days become a much more important factor in eastern WA as the region warms. In the Spokane metro area, for example, heating degree days decline by about 15% for the 2040 A1B scenario, but cooling degree days increase by 88%.Based on the work performed to date, our preliminary findings may be summarized as:

a) Heating degree days will continue to be the dominant energy-related factor into the 2020s and 2040s based on the A1B emissions scenario, but cooling degree days become a much more important factor in eastern WA as the region warms.
b) In the Spokane metro area, heating degree days will decline by about 15% in the 2040s compared to the historic condition, but cooling degree days will increase by 88%.

iv. Sensitivity to Climate Change and Potential for Adaptation

The preliminary assessment shows substantial changes in heating and cooling degree days in WA, including decreases in heating degree days in cool season and increases in cooling degree days in warm season. The seasonality of these changes has been shown in previous studies to be opposite to changes in hydropower production (increases in supply in winter, decreases in summer). These results suggest increased ability to meet electrical demand with local hydropower production in winter (increased supply, decreased demand), and increased difficulty in meeting energy demand in summer (decreased supply, increased demand). These projections suggest that adaptive measures should be focused on decreasing demand and/or increasing supply in summer.

Some possible broad-based strategies that would both adapt to expected changes in climate while reducing dependence on fossil fuels:

Table 6.2. Adaptation strategies for reducing the impact of climate change on the energy sector, in addition to reducing dependence on fossil fuels.

Strategy	**Adaptive Measure**	**Comments**
Decrease winter demand on hydro systems, increasing availability of hydropower resources in summer.	Establish state-wide space heating efficiency and insulation standards for new commercial and residential construction and provide economic incentives to retrofit existing lower efficiency equipment. Water conservation (via linkage to hot water use).	This strategy may also be a good "win-win" in the context of restoring instream flow in summer, because increased releases from hydropower dams in summer would also increase summer instream flow. Water conservation is a win-win because of expected reductions in water supply.
Reduce electrical energy demand and fossil fuel use by eliminating losses	Focus increases in temperature-related end use (heating, hot water, stoves,	Direct use of fuel in temperature-related end use applications can save 60-70%

associated with fuel-based electrical energy production, or by increasing the efficiency of end use applications	dryers) on natural gas or solar technology rather than fuel-based electrical energy production. In areas where fuel cannot be used directly in temperature related applications, increase efficiency of end use applications via geothermal heat pump technology or other approaches.	in comparison with generating electricity with the same fuel.
Reduce summer energy demand via end-use technology changes	Increase use of geothermal air conditioning systems or other high efficiency technologies. Establish state-wide air conditioning efficiency and insulation standards for new commercial and residential construction and provide economic incentives to retrofit existing lower efficiency equipment. Reduce heat island effects in urban settings via "green roofs" or other approaches. Water conservation (via linkage to hot water use).	Water conservation is a win-win because of expected reductions in water supply.
Increase summer energy supplies via increased renewable energy source capacity	Increase use of distributed renewable energy sources such as solar hot water heating and photovoltaic panels in residential and commercial buildings. Increase use of renewable energy resources in the commercial energy production sector to increase summer capacity.	
Increase transmission network capacity to deal with possible higher peak load in summer.	Assess and address transmission deficiencies to increase the capacity to deal with expected higher peak loads in summer.	(Use of distributed local solar technologies may be an effective way to address transmission deficiencies in the long term. I.e. if peak loads can be reduced, then

		increases in transmission capacity may also be avoided)
Increase awareness of energy use at the individual and community level as a means to promoting energy conservation.	E.g. Reduce unnecessary energy use such as standby losses from home electronics, increase use of high efficiency lighting technology, etc.	Many people have little or no idea *how* they are using energy in their homes and businesses nor *how much* energy they use.

v. Interactions with Water PAWG

The HB1303 energy sector, because it focuses mainly on hydropower production, falls within the scope of the Water Resources/Water Quality PAWG. The energy sector lead is also the CIG collaborator with the Water PAWG for the HB1303 water resources sector. Therefore, communications with the Water PAWG have encompassed water resources, energy, as well as salmon to some degree.

h. Human Health

i. Management/Decision Context and Research Needs

The management and decision context of climate impacts on health exists at multiple levels of government; federal, state, county and local agencies will have to be engaged in monitoring and adapting to potential health effects. Many health effects may be largely mitigated through emergency preparedness, public health planning and surveillance, and zoning and building codes that both reduce carbon emissions and enhance protection against heat extremes, poor air quality and disease vectors. The pathways through which climate change might affect human health are numerous and complex. Few effects are direct; most are mediated through features of the natural environment, the built environment, and social institutions. The most complex pathways involve relationships between environment, socioeconomic status, and exposure risk.

ii. Main Research Questions Addressed under HB1303

The overarching research question being addressed by the human health sector is: *What are the most problematic diseases and mechanisms through which climate change is most likely to affect the health of the people of the state, and what interventions can best be affected to mitigate or adapt to the predicted changes?*

Five mechanisms through which climate change is likely to affect health have been identified:

- thermal stress/heat waves
- degradation of air quality
- infectious diseases, especially vector-borne and zoonotic diseases (VBZ)
- extreme weather events affecting public safety
- psychological stress, social disruption and economic disparities

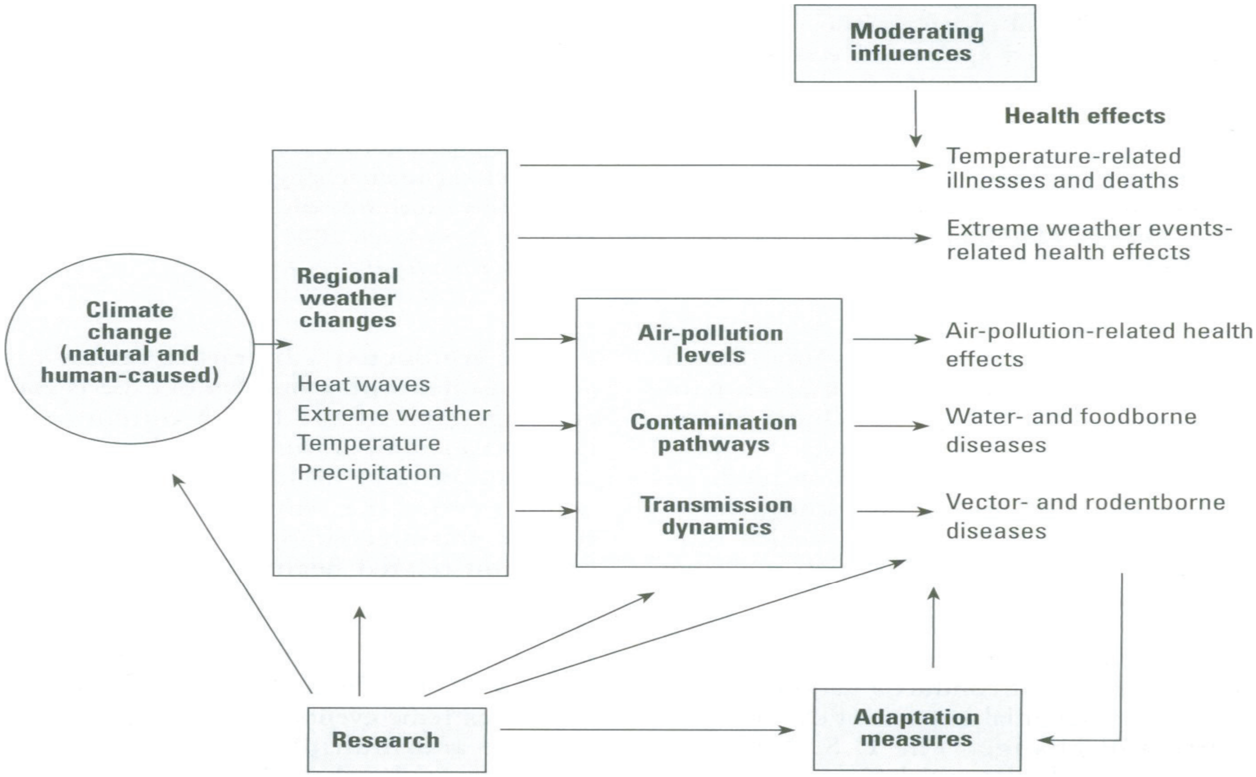


Figure 6.11. U.S. National Assessment model for impacts of climate change on human health (Patz et al. 2000).

The model developed for the U.S. National Assessment (Figure 6.11) provided the first four areas, heat stress, air quality, infectious disease (water and foodborne illness + VBZ), and extreme weather events. The fifth area, social disruption and disparities encompasses some of the social and economic factors that moderate the impact of climate on health.

iii. Scientific progress and Key Findings

The main results of this research to date are a synthesis of the existing literature, with special attention to issues likely to be relevant for Washington State. In addition, several empirical studies are in the planning stages that will establish baseline effects of climate parameters on human health that can then be applied to yield projected effects on human health. For example, one study will consider the relationship between emissions from recent wildfires and health effects as measured by smoke-related emergency room visits and hospital admissions.

Based on the work performed to date, our preliminary findings may be summarized by the following points:

a) Short, intense heat waves have been responsible for hundreds of deaths in the United States and thousands in Europe in recent years. As heat waves become more frequent, more intense and longer lasting, the greatest impacts will be felt in cities with milder summers, less air conditioning and higher population densities, which describes the major cities of Washington State.

b) The effects of climate change on air quality known to affect human health are increases in ambient concentrations of ozone and fine particulate matter, and a longer pollen season with increased allergenicity of some aeroallergens. Potential health effects are serious and include asthma, lung cancer, cardiovascular disease, and low birth weight or prematurity in newborns.

c) Increased temperatures and flooding may contribute to communicable disease by influencing the habitat and range of disease reservoirs and vectors, by shaping human behaviors that might lead to increased exposure to a disease or vector, and through effects on the characteristics of the disease pathogen, or on the immune response of the host. Important VBZ in Washington include Hantavirus pulmonary syndrome (spread by rodents), Vibriosis (raw shellfish), and mosquito-borne diseases such as malaria and West Nile virus.

iv. Sensitivity to Climate Change and Potential for Adaptation

Some aspects of human health are likely to be heavily influenced by climate change, especially chronic and acute illnesses related to heat and air quality, and infectious diseases. Chronic illnesses such as heart disease, hypertension, diabetes and asthma represent a substantial health burden in the United States, and may be exacerbated or caused by thermal stress and air pollutants. VBZ, because of the importance of animal and insect habitats for disease transmission and persistence, involve a large number of climate-sensitive variables; modeling the relationships between climate change and disease incidence will be challenging. Finally, some groups will be more vulnerable to climate impacts on health, including infants and children, the elderly, and especially those in poverty.

v. Interactions with Human Health PAWG

The health sector and the health PAWG have been working together closely since summer.
The health PAWG report submitted to the Department of Ecology was a coordinated effort of the two groups, and the current health sector report also comes out of that work. It is expected that contacts made at the Department of Health will be available to consult on subsequent research products.

7. Summary

a. Scientific "State of Knowledge"

The issue of global climate change has become increasingly important in the eyes of politicians, natural and human resource managers, and the public as a whole. In the 2007 IPCC AR4, the IPCC stated that climate change is unequivocal. Utilizing results from the AR4, as well as recent improvements to GCM data downscaling techniques and hydrologic modeling, put the CIG and Washington State on the forefront of understanding the impacts of climate change.

In the Pacific Northwest, based on GCM results, the expected increase in annual temperature in the 2020s is 1.2°C (2.1°F) for the B1 emissions scenario (which has slower increase of GHG emissions) or 1.3°C (2.3°F) for the A1B scenario (which has a more rapid increase of GHG emissions). In the 2040s, the expected increase in annual temperature is 1.7°C (3.1°F) for B1 and 2.3°C (4.1°F) for A1B. The projected increase in annual average precipitation is 1.8% for the B1 scenario and 0.1% for the A1B scenario in the 2020s. In the 2040s, the projected increase is 2.1% for B1 and 2.0% for A1B. In general, results indicate greater increases in precipitation during winter months and decreases in precipitation during summer months. Our best estimate of sea level rise for most coastal waters of Washington is 15cm (6 inches) by 2050 and 35cm (14 inches) by 2100.

The CIG HB1303 work utilizes the most current data and modeling approaches to assess the impacts of climate change. Results presented in this interim report are a preview of what will be presented in the final report in 2008.

b. Discussion of Climate Change Sensitivity

The SOW dated July 2007 states that as part of the interim report CIG will identify the most sensitive of the nine sectors to climate change. Preliminary findings suggest that all sectors are sensitive to climate change and as such, the sector interim results and findings (Section 6) discusses areas of high and low sensitivity to climate change for each sector. Climate sensitivities are summarized by sector below.

a) Hydrology – Water resources are highly sensitive to climate change due to the small percentage of river flow that may be stored in the State's reservoirs. As temperatures become increasingly warm, less precipitation will be stored as mountain snowpack and will therefore continue to alter the timing of seasonal flow in our rivers and streams.

b) Agriculture and Irrigation Agriculture/Economics – Warmer temperatures may pose a large burden on the tree fruit industry. Potatoes are sensitive due to the relatively low temperature required for tuber initiation and the crop's susceptibility to diseases and other pests. With respect to grapes, shifts in the variety makeup of different regions within the state and the decrease of suitable areas can be expected. With respect to dryland agriculture, marginal production areas on the warm, dry end of the climate spectrum may not support agriculture in a warmer climate.

c) Salmon – Survival of anadromous and resident fish alike depends on hydrologic processes that influence stream flow timing, volume, and stream temperature and these are highly sensitive to climate variations.

d) Forests - Most key processes (e.g., disturbance) in forest ecosystems are sensitive to climate change; however, changes in climate will most likely first affect forests that are currently at the edge of the forest distribution (particularly lower treeline).

e) Coasts - Sea level rise and the associated coastal changes are projected to happen gradually over time. However, the coast is particularly sensitive to low-frequency high-impact storm and erosion events that are difficult to predict.

f) Infrastructure – Areas most sensitive to climate change include those urban areas that already have poor stormwater drainage together with little undeveloped land on which to construct new (or expand existing) facilities.

g) Energy – The hydropower industry is sensitive to a warming climate because it will cause increases in the ability to meet electrical demand with local hydropower production in winter (increased supply, decreased demand), and increased difficulty in meeting energy demand in summer (decreased supply, increased demand).

h) Human Health - Aspects of human health are likely to be sensitive to climate change, especially chronic and acute illnesses related to heat and air quality, and infectious diseases.

c. Future research agenda priorities

The CIG will prepare chapters of the final report such that they are suitable for peer reviewed journal publication. Over the course of the project, the CIG will identify areas where future research is needed. The possibility exists that cross-cutting issues will emerge as research progresses in a similar way as between the PAWGs (for example, the fact that salmon emerged as important themes in both the water and forest PAWGs). Along with any high-priority research gaps, the CIG will identify any cross-cutting themes in the final report.

d. Anticipated directions for Final Report

The CIG will complete analyses for the final report for the eight sectors (Hydrology, Agriculture, Irrigated Agriculture, Salmon, Forests, Coasts, Infrastructure, Energy, and Human Health) corresponding with the Scope Of Work. The final report will also discuss approaches for adaptation and address legal barriers to adaptation, in coordination with PAWG recommendations presented in the final PAWG report in February 2008 and implementation of recommendations made during 2008. This will be done both at the individual sector level as well as at the overall project level.

A draft final report will be completed by November 16, 2008 and will be posted and otherwise circulated as CTED prescribes for public comment, and for technical review by reviewers to be selected by CTED in consultation with CIG, if CTED so desires. The final report will be structured to include an introductory chapter, one chapter or more for each of the nine sectors, and a chapter including conclusions and findings. Each chapter will be written in suitable form for review as a stand along peer reviewed journal publication. The final report will be complete on or by December 31, 2008.

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